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CITIZEN AND TECHNOLOGY: THE CORE IN DEVELOPING HUMAN-CENTRIC SMART CITIES

Mohammed Ali Berawi[1,2*], Mustika Sari[1,2], Perdana Miraj[2]

[1]*Deparment of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia*
[2]*Center for Sustainable Infrastructure Development, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia*

As urbanization continues to grow, the development of smart cities has become a pivotal strategy for addressing the complex challenges of modern urban living. These cities harness advanced technologies like the artificial intelligence (AI), Internet of Things (IoT), and Digital Twin to optimize city operations, improve sustainability, and enhance the quality of life for their residents. However, the success of smart cities should not be measured by the sheer quantity of hardware and software implemented but rather by the quality of life they create for the people who live and work within them. In other words, smart cities must prioritize human well-being as a core goal alongside technological advancement.

In a smart city, hardware encompasses the physical infrastructure and devices, such as sensors, data centers, communication networks, energy grids, and other tangible components that gather data, facilitate communication, and support the city's operations. The software includes the digital systems, algorithms, and applications that process and analyze data, which facilitate decision-making, predictive analysis, and automation. However, neither hardware nor software can operate well without *brainware*, the human operators who oversee, maintain, and interact with these systems, as well as the citizens who utilize the smart city services offered.

For a smart city to be successful, its *brainware* must possess the requisite knowledge, skills, and mindset to manage the technologies and adapt to their dynamic nature. It involves ensuring that city planners, public officers, and citizens are not merely passive consumers of technology but active participants who understand how to utilize the available resources to enhance their lives and communities. Smart citizens can interact with surrounding technology, which enable informed decision-making and enhancing the sustainability and governance of the city. Likewise, smart operators overseeing smart systems must have the skills to analyze data, resolve problems, and make decisions that improve the efficiency and safety of urban operations.

Brainware is vital for maintaining the smart city ecosystem, since human decision-making and oversight are important for the successful integration of technology. Therefore, city operators must possess the ability to comprehend and adapt to emerging technologies and complex systems so that the seamless functioning of all smart city systems can be guaranteed. To acquire *brainware*, a holistic strategy in education and training is needed, which includes building technological literacy and developing critical thinking, problem-solving, and collaborative skills.

*Corresponding author's email: maberawi@eng.ui.ac.id
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Moreover, it is also essential to ensure that all citizens, irrespective of their age, background, or digital literacy, are included in the smart city ecosystem by providing equitable access to technology and information. Therefore, community participation can be encouraged and citizens' digital literacy of citizens can be improved, which can further enable collective decision-making and responsible resources use.

Consequently, the development of smart cities should not solely be limited only on the hardware and software but should also prioritize the development of *brainware*. We can establish cities that are not only technologically advanced but also socially inclusive by guaranteeing that the city operators are trained and that citizens are empowered to interact with the smart city technologies. A comprehensive approach that integrates hardware, software, and *brainware* will ensure the development of smart cities that are inclusive, resilient, and capable of safeguarding a sustainable future for urban living.

Research in Urban Planning, Technology, and Management: Advancing Knowledge for Human-Centric Cities

It is important to conduct research in urban planning, technology, and management to enhance our comprehension and create innovative solutions that will improve the well-being of urban citizen. The CSID Journal of Infrastructure Development presents a series of nine papers in this edition that offer valuable insights into this area.

The first paper, written by A.O. Noah and O.O. David, examines the role of external financing, such as Official Development Assistance (ODA), Foreign Direct Investment (FDI), and Private Participation in Infrastructure (PPI), on the development of infrastructure in Sub-Saharan Africa. The study emphasizes the critical role that governance plays in mediating the impact of these financing sources. The results indicate that FDI has a significant impact on physical infrastructure but has minimal impact on social infrastructure. The paper also discusses the negative impact of ODA on infrastructure development and proposes recommendations to improve external financing strategies and governance to promote sustainable infrastructure growth.

The second paper, written by C.C. Adindu, A. O. Muhammed, E.A. Egila, and M. Mohammed, analyzes the risk performance of mass housing projects in Northern Nigeria. The findings show that insufficient risk management deters timely delivery, budget adherence, and quality standards. The study evaluates information risks associated with project roles, responsibilities, scope, and operations in order to identify critical vulnerabilities, including underfunding and inadequate monitoring. The paper suggests a risk management framework to resolve these issues, further providing actionable insights to enhance project outcomes and align them with end-user requirements.

The third paper, written by Y.T. Suryana and A. D. Rarasati, focuses on the strategic implementation of knowledge management (KM) practices to facilitate technology transfer in Indonesian Joint Operation (JO) construction projects. Their research identifies key KM processes, which include knowledge acquisition, sharing, and utilization, that can bridge gaps between local capacities and advanced technologies introduced by foreign partners. The study provides a tailored framework for improving technology transfer efficiency in Indonesia's infrastructure projects.

The fourth paper, written by M. E. Ohida, I. Imam, and A. O. Ajiboye, investigates logistics factors influencing the procurement of construction materials in Lokoja, Kogi State. Through survey data and statistical analysis, the study identifies critical factors like on-time delivery, transportation challenges, and material misdelivery that affect procurement efficiency. The paper concludes that better coordination and management of logistics are essential to avoid delays and cost overruns in construction projects.

The fifth paper, written by P. Onibaba, K. V. Otokiti, O. G. Ademola, and T. Akanle, explores the relationship between land use/cover (LU/C) changes and land surface temperature (LST) in Kaduna State, with a particular emphasis on the Surface Urban Heat Island (SUHI) effect. The study finds that urbanization has had a substantial impact on LST, particularly in densely populated areas. The research emphasizes the need for sustainable urban planning and design strategies to mitigate SUHI effects. It offers recommendations to reduce urban heat through better land use management.

The sixth paper, written by A. S. Olatunji, E.A. John, A. A. Adedeji, and M. L. Mikaila, assesses the state of public parking facilities in Keffi Town, Nigeria, identifying significant issues such as congestion, insufficient parking spaces, and lack of modern parking management systems. The study suggests improvements in infrastructure, safety, and regulatory enforcement to enhance parking efficiency and urban mobility in the growing town

The seventh paper, written by S. B. Ariyadi and W. W. Purwanto, evaluates the techno-economic feasibility of 10 MW grid-connected solar photovoltaic (PV) systems in Indonesia, by comparing scenarios with and without Battery Energy Storage Systems (BESS). The study finds that solar PV without BESS is economically viable, however, the addition of BESS results in an increase in costs. To enhance the feasibility of BESS projects and accelerate the renewable energy adoption in Indonesia, this research recommends policy interventions, such as tariff adjustments and competitive auctions.

The eighth paper, written by A. L. S. Ingles, discusses the integration of environmental stewardship and social justice in the Philippines through the framework of *Laudate Deum*. It examines case studies of local environmental initiatives and the socio-economic impacts, highlighting the significance of community participation and alignment of policies with social justice goals to mitigate ecological degradation and promote sustainability in Southeast Asia.

The ninth paper, written by M.O. Audu and O. M. Adeiza, provides comprehensive overview of Nigeria's infrastructure development from 2014 to 2023, with a focus on transportation, energy, and housing projects. Despite some achievements, the study highlights persistent challenges such as inadequate funding, regulatory inefficiencies, and security issues that delay progress. The paper proposes strategic recommendations to improve infrastructure quality, accessibility, and sustainability to support long-term economic development in Nigeria.

We hope this edition may convey new insight and knowledge that benefit our readers. We welcome any comments or inquiries that you may have concerning the direction and the content of this journal. We invite you to join our venture by sending your work for future consideration.

Warmest regards from the Editorial Office,

Prof. Mohammed Ali Berawi
Editor-in-Chief

Dr. Mustika Sari
Managing Editor

Perdana Miraj
Managing Editor

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EXTERNAL FINANCING, GOVERNANCE, AND INFRASTRUCTURE DEVELOPMENT: EVIDENCE FROM SUB-SAHARAN AFRICA

Afees Oluwashina Noah[1*], Oladipo Olalekan David[1]

[1]*Economic Sciences, Faculty of Economic and Management Sciences, North-West University, South Africa*

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ABSTRACT

Infrastructure development in Sub-Saharan Africa (SSA) requires diversified financing strategies to address a significant funding shortfall that cannot be met by domestic resources alone. This research evaluates the contributions of external financing—namely Official Development Assistance (ODA), Foreign Direct Investment (FDI), and Private Participation in Infrastructure (PPI)—in complementing domestic efforts to advance infrastructure in SSA. It examines their influence, alongside governance, on the development of physical and social infrastructure components. Employing methodologies such as Panel-Corrected Standard Errors (PCSE) and System Generalized Method of Moments (SGMM) across 43 SSA economies from 2000 to 2022, the analysis reveals that FDI substantially enhances physical infrastructure development but does not significantly impact social infrastructure. In contrast, ODA is shown to have a negative direct effect on overall infrastructure development, whereas PPI shows no significant direct influence. However, when considering indirect effects mediated by governance, all external financing sources positively affect both types of infrastructure, except for PPI's influence on social infrastructure. Theoretically, this study reinforces the critical roles of economic growth, institutional quality, and external financing in supporting infrastructure development, as suggested by related theories. The study recommends that SSA authorities should focus on attracting more foreign investment, particularly in physical infrastructure projects, and encourage a broader diversification of external financing sources beyond FDI alone. Moreover, enhancing governance practices is essential for effective resource allocation and utilization. The study also advocates for improved public spending efficiency through enhanced project prioritization and governance reforms to foster sustainable infrastructure development in the region.

Keywords: External financing factors; FDI, ODA; PPI; Governance; Infrastructure development; Physical and social infrastructure; Sub-Sahara Africa

1. INTRODUCTION

Governments around the globe face mounting pressure to implement robust policies to counteract the economic challenges triggered by the COVID-19 pandemic (Chan et al., 2022). Infrastructure development plays a pivotal role in fostering investments and stimulating economic growth, as evidenced by prior research (Maciulyte-sniukiene, 2022; Mallek et al., 2024; Ngundu & Ngalawa, 2023). Insights from emerging economies underscore that infrastructure investments are indispensable for achieving sustainable development. Nevertheless, Africa's infrastructure remains markedly underdeveloped, necessitating significant financial resources and sustained efforts to realize its full potential (Cédric et al., 2024).

*Corresponding author's email: noahafees@gmail.com
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Inadequate infrastructure in most African countries has led to a 2% annual decline in national economic growth and a 40% reduction in industrial output (African Union, 2023). Specifically, Sub-Saharan African (SSA) countries continue to lack the sustainable and sufficient infrastructure necessary to support accelerated economic growth (Nnyanzi et al., 2022). For instance, although all African nations experienced improvements in their Africa Infrastructure Development Index (AIDI) scores between 2018 and 2020. The continent's average score only increased marginally from 28.44 to 29.63. The top ten performing countries saw their indices rise from a range of 36.7–94.32 in 2018 to 35.50–96.73 in 2020. Meanwhile, the ten lowest-ranked countries showed more modest improvements, with index scores increasing from 3.62–12.50 in 2018 to 4.53–12.60 in 2020. Notably, the overall improvement is largely attributed to progress in the Information and Communication Technology (ICT) and water and sanitation sectors (African Development Bank - AfDB, 2022).

Due to persistent funding shortfalls, inadequate maintenance, and mismanagement, much of SSA's infrastructure remains in poor condition (World Bank, 2024). Despite some progress in areas like water, sanitation, and telecommunications, critical gaps endure (Noah, 2021). Financing remains one of the most significant challenges for infrastructure development on the continent, as domestic resources often fall short of meeting these needs (Lu & Wilson, 2024). Historically, SSA governments have primarily depended on domestic funding for infrastructure projects. However, as Lu and Wilson (2024) note, competing fiscal priorities and strict budgetary constraints have limited their capacity to allocate sufficient resources, thereby delaying progress toward improved living standards.

To address the constraints of limited domestic funding, exploring and prioritizing external financial resources is imperative for mitigating the infrastructure deficit in SSA nations. In addition to domestic funding, external sources such as foreign direct investment (FDI), private participation in infrastructure (PPI), and official development assistance (ODA) have played key roles in advancing infrastructure development, especially since 2005 (The Infrastructure Consortium for Africa, 2010). Foreign investments in infrastructure present numerous advantages for developing countries, including closing critical funding gaps (Nam et al., 2023). Nevertheless, the connection between external funding and developmental outcomes remains complex, particularly in low-income regions where governance quality often dictates success (Wang & Zhuang, 2021).

Governance has become a focal point in discussions about infrastructure financing and development, with stakeholders increasingly scrutinizing the management, accountability, and operational frameworks of both national and international institutions. Effective governance is pivotal in creating a conducive environment for infrastructure progress. High standards of governance, including anti-corruption measures and institutional effectiveness, are critical for ensuring that external financing achieves its intended objectives. Conversely, inefficiencies, political rent-seeking, and corruption often plague privatization processes, undermining development initiatives. For example, structural adjustment programs (SAPs) introduced in SSA to stimulate infrastructure growth were often derailed by weak leadership and governance shortcomings (Zúñiga & Mullard, 2018).

Analyzing how external financing interacts with governance quality in recipient countries can offer valuable insights into the role of effective governance in mediating the link between external funding and infrastructure development in SSA nations. Surprisingly, this area has received limited attention in the relevant literature, and the current study seeks to address this gap. The study contributes to the existing literature by measuring infrastructure development using a composite infrastructure index comprising six key indicators: water, energy, transportation, telecommunications, health, and education. These indicators are further categorized into two

primary components—physical and social infrastructure—and the study examines the differential effects of external financing factors, as well as control variables, on both components of infrastructure development. While most recent studies in this field (Appiah et al., 2022, 2024; Cédric et al., 2024; Lu & Wilson, 2024) have utilized the African Development Bank's Africa Infrastructure Development Index (AIDI), which began in 2005, these studies primarily focus on the liberalization period of the late 1990s to early 2000s in SSA and are mainly concerned with physical infrastructure indicators, except for water and sanitation. While these findings are valuable, a comprehensive assessment of the main drivers of various infrastructure components is still required. Such an evaluation is crucial for designing policies that effectively allocate scarce resources and plan for the development of different infrastructure components.

Previous research has primarily focused on how infrastructure impacts specific external financing factors rather than examining the reverse relationship. Most studies have concentrated on FDI and PPI or PPP (Lu & Wilson, 2024; Zhao et al., 2024). For example, Ur-Rehmana et al. (2020), Waqar et al. (2020), and Shinwari et al. (2024) assessed the impact of FDI or PPI on physical infrastructure but limited by their analysis on physical infrastructure indicators alone, excluding studies conducted within SSA context. Consequently, there has been insufficient research examining the combined impacts of major external financing sources—FDI, PPI, and ODA—on infrastructure development in SSA. The limited number of studies addressing this topic often focus on one financing source at a time instead of evaluating all three simultaneously as infrastructure development drivers

This study adopts the simple accelerator theory of investment alongside the Two-Gap and Game theories to develop a comprehensive framework for analyzing infrastructure development and its components. Unlike earlier studies, which often lacked a unified theoretical foundation, this research aims to bridge that gap. It examines the role of external financing factors in shaping infrastructure development, emphasizing governance quality as a crucial mediating variable. The interplay between governance, external funding, and infrastructure outcomes is complex and requires a nuanced understanding of SSA's social, economic, legal, cultural, and political dynamics. A review of prior studies highlights a significant void in analyzing how governance mediates the relationship between external financing sources and infrastructure outcomes. This theoretical and empirical gap underscores the importance of exploring governance as a moderating factor in infrastructure financing. To our knowledge, no prior research has comprehensively addressed the combined influence of governance and external funding mechanisms on SSA's infrastructure development.

This study aims to close these gaps by evaluating the influence of external financing factors on infrastructure development in Sub-Saharan Africa. Specifically, it focuses on how these financing sources affect the two critical infrastructure components: physical and social infrastructure. Additionally, the study investigates governance's mediating role in shaping the impact of external funding on infrastructure outcomes. By analyzing the distinct and collective effects of external financing factors on infrastructure systems and their components, the research contributes new insights. The subsequent sections of this study outline the methodology, findings, and policy recommendations.

2. REVIEW OF RELATED THEORETICAL AND EMPIRICAL STUDIES

2.1. Theoretical Perspective on Infrastructure Financing

The concept of "infrastructure" covers an extensive range of elements, including both social and economic resources (Nakamura et al., 2019). It encompasses the foundational services that enable social and economic activities within a community, such as water supply, sanitation, electricity, telecommunications, healthcare, education, and transportation systems. Developing infrastructure entails constructing and improving these essential services, which are vital for

driving economic growth and enhancing overall quality of life (Noah, 2021). Infrastructure is typically classified into two primary categories: social infrastructure and physical infrastructure. Social infrastructure focuses on services that directly or indirectly improve human welfare, including healthcare and education. On the other hand, physical infrastructure—often referred to as economic infrastructure—facilitates economic activities through systems such as roads, railways, highways, airports, seaports, energy networks, and telecommunications (Islam et al., 2022).

Physical and social infrastructure share an interdependent relationship. Physical infrastructure lays the groundwork for the effective delivery of social services, while well-developed social infrastructure ensures a skilled, healthy, and educated population capable of sustaining and managing physical infrastructure. This synergy drives societal development and fosters economic growth (Reilly et al., 2021). Both forms of infrastructure are indispensable for sustainable development, serving complementary roles in improving economic performance and societal well-being. Physical infrastructure supports trade, investment, and the seamless movement of goods and people, contributing directly to economic growth and better living conditions. At the same time, social infrastructure ensures a cohesive, healthy, and educated society that can actively participate in economic activities. Together, these two types of infrastructure provide the foundation for robust economic activities and a high standard of living, making them essential for long-term development and prosperity (Jonek-Kowalska, 2022).

External financing encompasses various sources of funding from outside a country, which, when utilized effectively, can support development in recipient nations. These funding sources include contributions from non-governmental organizations, commercial and non-commercial private flows, as well as official bilateral and multilateral funding mechanisms (McHugh, 2021).

This study recognizes the absence of a widely accepted theory specifically addressing the supply side of infrastructure (the infrastructure supply model), despite the numerous theories and schools of thought related to funding and development. To analyze infrastructure development, this study draws on the Accelerator Theory of Investment, Game Theory, and the Two-Gap/Dual Gap Model, as these theories offer valuable insights into the dynamics of infrastructure financing and development.

The Two-Gap Model of development identifies the essential conditions required for economic growth in market-based economies, particularly those in emerging markets. The first condition, referred to as the savings-investment gap, emphasizes that many developing nations, including those in SSA, experience insufficient domestic savings due to low per capita income. This shortfall limits their ability to generate the investment necessary for development. The second condition, known as the trade gap, highlights the inability of these nations to produce sufficient foreign exchange to support economic growth, primarily because of limited competitiveness in global markets. To address these gaps, external financial support is often essential. This model is relevant to this research as it underscores the critical role of external funding in infrastructure projects designed to foster economic growth and development. However, the model's focus on funding rather than the broader dimensions of infrastructure development represents a key limitation, which this study aims to address.

The Principal-Agent Theory, which examines the critical dynamic between principals and agents, provides another theoretical framework relevant to this study. It describes scenarios where a principal delegates authority to an agent, which may sometimes lead to unfavorable outcomes due to misaligned interests or misunderstandings. This theory heavily relies on the assumption that agents act in the principal's best interests (Moe, 2005). Challenges often arise when entities like governments (principals) and citizens (agents) have conflicting priorities or unequal access to information. This study applies this theory to explore how governance, acting as the agent of

the citizens (principals), mediates the effects of external financing on infrastructure development. Transparency and accountability are essential for overcoming these agency problems. Effective governance plays a crucial role in ensuring stakeholder participation, improving access to critical information, and enhancing service delivery (Noah, 2023).

This framework highlights the importance of effectively allocating external funding for infrastructure and development projects. In many SSA nations, governments and international donors (as principals) provide financial resources and oversee development projects, while local stakeholders (agents) are tasked with their implementation. However, inefficiencies such as corruption, weak accountability, and inadequate governance often lead to resource misallocation. By utilizing the Principal-Agent Theory, these issues can be analyzed and addressed by emphasizing mechanisms such as proper monitoring, transparent systems, and appropriate incentives. These measures help ensure that agents act in the best interest of the principals, leading to better infrastructure outcomes and improved governance.

The investment accelerator theory, a variant of the neoclassical investment theory, is based on the premise that output levels determine capital stock. Essentially, there exists a fixed relationship between output and capital stock, meaning that the level of output at any time corresponds to the capital stock. In SSA, factors like population growth and urbanization drive increased demand for goods, services, and infrastructure. Governments and businesses respond to this demand by expanding and initiating new projects. The theory suggests that this process creates a positive feedback loop: rising demand drives investment, which in turn stimulates economic activity, further increasing demand. However, to sustain this cycle, barriers such as limited access to capital, regulatory challenges, and infrastructure deficits must be addressed. With its mathematical basis and emphasis on real investments linked to output, this theory provides a relevant framework for examining infrastructure development in SSA.

2.2. Empirical Review

Most research on infrastructure has focused on benefits for economic growth and development (Kuete & Asongu, 2023; Liu et al., 2023; Mubin, 2019). Moreover, other studies have also examined the effects of infrastructure on general well-being, such as employment, poverty, inequality, the environment, and business outcomes (Awad et al., 2023; Berawi et al., 2021; Ketu et al., 2024; Noah, 2023; Sharma et al., 2022). Additionally, some research has explored various methods of financing infrastructure (Berawi et al., 2023; Smaoui et al., 2021), while other studies have investigated the determinants of infrastructure and its indicators, often through systematic reviews focusing on physical infrastructure (Chan, Jin, & van Kan, 2022; Grobe, 2023; Na et al., 2020; Revko, 2021). However, there is a notable lack of research specifically addressing external financing for infrastructure development in SSA. The limited research that does exist typically examines the impact of infrastructure on attracting external financing factors such as FDI and PPI (Mensah & Traore, 2023; Ross, 2019; Ur-Rehmana et al., 2020; Zhao et al., 2024).

However, recent research has focused on the relationship between governance and the physical infrastructure development. For example, Ali and Bhuiyan (2022) investigated the link between natural resource rents and governance, concluding that improved governance positively impacts physical infrastructure development in the Middle East and North Africa. Similarly, Appiah et al. (2022) explored the influence of institutions and governance on infrastructure development in SSA countries, finding that strong institutional quality and governance are critical for infrastructural growth. In a more recent study, Appiah et al. (2024) highlighted the moderating institutional quality's role in the relationship between infrastructure development and the governance, which show that the interaction happening between the institutional quality measures and governance indicators can significantly promote SSA's infrastructure development.

Other research by Berawi et al. (2023) and Cédric et al. (2024) have explored the impact of various infrastructure financing mechanisms, including insurance funds on infrastructure development in Indonesia and SSA countries, respectively. Berawi et al. (2023), suggest that insurance funds could be an alternative financing source for infrastructure development projects. However, Cédric et al. (2024) found that while insurance does not directly impact telecommunications infrastructure, it positively influences the development of aggregate infrastructure, as well as transportation, energy, and water and sanitation infrastructure. In a study focused on Indonesia, Fawwaz et al. (2021) explored the contribution of Waqf, an Islamic charitable endowment, to infrastructure development. They argued that, while the lack of skilled Waqf managers presents significant challenges, Waqf assets could become a viable funding source for infrastructure projects if effectively managed. Likewise, Smaoui et al. (2021) investigated the role of Sukuk, a Sharia-compliant financial instrument, in advancing infrastructure development across 15 developing nations. Their findings suggest that a well-developed Sukuk market can support infrastructure growth. However, they also noted a potential competitive dynamic between Sukuk and conventional bond markets, as strong bond markets might crowd out Sukuk-based infrastructure financing, which indicates a need to balance these funding mechanisms to optimize infrastructure investment.

Lu and Wilson (2024) emphasize the importance of equity investment as a key mechanism for financing infrastructure in the African countries that were least developed, where debt financing options are often limited. In South Africa, Phalatse (2022) explored the role of private financing in infrastructure development, highlighting that, despite the country's substantial infrastructure deficit, the state's critical role in fostering structural economic transformation is frequently overshadowed by efforts to reduce risks for private sector participation. In Pakistan, Ur-Rehmana et al. (2020) identified a long-term, bidirectional causal relationship between FDI and infrastructure development. Waqar et al. (2020) demonstrated that Chinese FDI has had a significant positive effect on infrastructure advancement in African nations. Similarly, Shinwari et al. (2024) analyzed the influence of FDI on energy consumption across 29 economies involved in the Belt and Road Initiative (BRI) from 2000 to 2021, concluding that both Chinese and global FDI positively impact energy consumption.

Despite the expanding body of research on the relationship between infrastructure and governance, no comprehensive study has examined both social infrastructure and physical infrastructure within a unified framework. The majority of previous studies have concentrated primarily on physical infrastructure. Moreover, the few studies that have investigated the role of external financing in infrastructure development have mainly focused on FDI or PPI, both of which are relatively uncommon in SSA. Earlier research has predominantly analyzed how infrastructure influences external financing factors, rather than exploring the reverse relationship. Additionally, most studies have addressed the direct impacts of governance and external financing on infrastructure while often neglecting their indirect effects. Consequently, there remains a limited understanding of how external financing pathways contribute to infrastructure development in SSA.

This study utilizes Principal Component Analysis (PCA) to create a composite index for infrastructure, encompassing both physical components such as energy, transportation, and telecommunications, and social components (education, health, water and sanitation). Additionally, to assess the impact of governance on infrastructure development and its various elements, a composite governance index is constructed based on six key governance indicators.

3. METHODS

3.1. Model Specification

Key variables analyzed in this study, including governance and external financing factors (FDI, PPI, and ODA), are grounded in the Two-Gap and Game theories. Unlike conventional investment models, which often treat investment as a fixed financial or business activity, the accelerator theory of investment conceptualizes investment as real or capital investment, hence, the relevance to this research. This theory is based on the assumption that the capital-output ratio remains relatively constant, implying that the capital stock is proportionate to the output level at any given period *t*. This can be expressed as:

$$K_t = \sigma Y_t \tag{1}$$

where K_t represents the capital stock, Y_t represents the output level, σ is the capital-output ratio and *t* is time. This formulation provides the basis for further analysis in this study.

The model in this study is an extension of the basic accelerator theory of investment, incorporating additional control variables such as population, urbanization, government capital expenditure, and domestic financial development, as supported by the literature (Ali & Bhuiyan, 2022; Noah, 2021). Beyond the output level, which determines infrastructure development in Equation (1), the model emphasizes governance and external financing factors (FDI, PPI, and ODA) based on the Two-Gap and Game theories. Taking both theoretical and empirical justifications into account, the model to achieve the objectives of this study is specified as follows:

$$KIN_{it} = \theta_0 + \theta_1 OUT_{it} + \theta_2 EXT_{it} + \theta_3 QOG_{it} + \theta_4 X_{it} + \omega_{it} \tag{2}$$

where KIN represents the composite index of infrastructure generated through PCA as a proxy for infrastructure development, OUT refers to the output level measured by GDP per capita, and EXT includes disaggregated external financing factors—FDI, PPI, and ODA (each expressed as a percentage of GDP). The quality of governance QOG is measured by a composite index of six governance indicators derived using PCA. The control variables, X, consist of population (measured by population density), urbanization (percentage of urban population to total population), total government capital expenditure (expressed as a percentage of GDP), and domestic financial development (index). The error term is denoted by ω, θ_0 represents the intercept, and θ_1 - θ_4 are the slope coefficients, while t and i represent time and country, respectively.

The inequality notations of the a priori expectancies of each variable parameter are expected to be positive, based on the analysis of the models. This is justified by the widely accepted view that external financial sources contribute positively to infrastructure development (Shinwari et al., 2024; Tei & Ferrari, 2018; Waqar et al., 2020). Studies on infrastructure often use GDP as an indicator to measure the volume of demand and income in an economy. As noted by Ali and Bhuiyan (2022), and Noah (2021), an increase in economic activity provides an opportunity to improve infrastructure. Equation (1) supports the flexible accelerator theory of investment, emphasizing that governance quality is also expected to positively influence infrastructure development due to its significant role in enhancing infrastructure outcomes (Ali & Bhuiyan, 2022; Appiah et al., 2022).

Furthermore, the growth of a country's financial sector is expected to positively impact infrastructure development, as it facilitates the capital-raising process needed for infrastructure projects (Berawi et al., 2023; Cédric et al., 2024; Smaoui et al., 2021). Given that providing infrastructure is a core responsibility of the government, increasing capital expenditures from the

public budget is anticipated to have a significant positive effect on infrastructure development (Cerra et al., 2017). One of the key challenges is providing infrastructure that can accommodate the demands of a growing population and urbanization. To meet societal needs, developed cities must build, maintain, and upgrade their extensive infrastructure systems (Tei & Ferrari, 2018). Based on the theoretical and empirical literature, it is expected that governance and external financing factors will drive infrastructure development. Therefore, this study proposes the following hypotheses:

H1: External financing factors could strengthen infrastructure development and its components in SSA countries.

H2: Governance could strengthen infrastructure development and its components in SSA countries.

H3: Governance would strengthen the positive impact of external financing factors on infrastructure development and its components in SSA countries.

3.2. Methods of Analysis and Data Measurement and Sources

The analytical methods used in this study include descriptive statistics, correlation analysis, and panel data regression. Descriptive statistics summarize key information such as the mean, standard deviation, and minimum and maximum values of the variables. Correlation analysis is performed to evaluate multicollinearity by examining the correlation coefficients between pairs of model variables. Panel data regression is employed to analyze the long-term relationships among infrastructure development, governance, and external financing, utilizing the panel-corrected standard error (PCSE) technique.

To validate the regression results, pre-estimation diagnostic tests are conducted, including unit root tests, cointegration tests, and cross-sectional dependence checks. The PCSE estimation method is selected over panel OLS, fixed effects, and random effects models because it effectively addresses issues such as serial correlation, heteroscedasticity, and cross-sectional dependence. This approach is particularly well-suited for this study, as the number of time periods (T) is smaller than the cross-sectional dimension (N). Although feasible generalized least squares (FGLS) is another option, PCSE generally provides better performance, especially when T is less than N (Beck & Katz, 1995; Reed & Webb, 2010).

To further corroborate the PCSE estimates, this study also employs the System Generalized Method of Moments (SGMM) for robustness, chosen for its ability to address endogeneity issues, allowing for a greater number of moment conditions and accommodating complex data structures. It is particularly efficient in dynamic panel data models, providing more accurate parameter estimates. The results from the SGMM are presented in the appendices for brevity.

From 2000 to 2022, annual data for 43 SSA countries were collected from various secondary sources. The selection of countries and the time frame are primarily determined by the availability of data, particularly for governance and telecommunications infrastructure. Data on GDP per capita, population, urbanization, water, and governance indicators were obtained from the World Bank's World Development Indicators. Information on financial development was sourced from the International Monetary Fund's (IMF) International Financial Statistics, while government capital expenditure data were provided by the African Development Bank (AfDB). Health data were sourced from the World Health Organization (WHO), education data from the United Nations Educational, Scientific and Cultural Organization (UNESCO), and telecommunications infrastructure indicators (such as subscriptions to telephone, mobile phone, and the Internet) from the International Telecommunication Union (ITU). The study further evaluates a comprehensive range of infrastructure indicators, incorporating both physical and social infrastructure components, in contrast to previous studies that have typically focused on a specific indicator or

aspect, such as physical infrastructure (e.g., energy, transportation, and telecommunications). A single composite index for energy, transportation, telecommunications, education, health, and water was developed using PCA due to potential correlations among the infrastructure metrics. The initial step in constructing the composite infrastructure index involves taking the residuals from the regression of each infrastructure component (David, 2019; Noah, 2021). The residual series from these regressions are then combined using PCA. The initial eigenvectors from the PCA are utilized as weights to create an aggregated index for infrastructure development, resulting in the following linear combination:

$$KIN = \varphi_1 eny + \varphi_2 com + \varphi_3 tst + \varphi_4 hth + \varphi_5 etn + \varphi_6 war \quad (3)$$

where φ_1, φ_2, φ_3, φ_4, φ_5, and φ_6 represent the eigenvectors (weights) obtained from the PCA, while eny, com, tst, hth, etn, and war denote the indicators for energy, telecommunications, transport, health, education, and water, respectively. The same methodology is applied to construct composite indices for governance, social infrastructure, and physical infrastructure.

Building on the theoretical framework and the justification of variables, the analytical techniques employed to achieve the study's objectives include descriptive statistics, correlation analysis, pre- and post-estimation diagnostic tests, and panel regression analyses.

4. RESULTS AND DISCUSSION

4.1. Descriptive, Correlation, and Pre-Estimation Results

Table 1 Descriptive Statistics

Variables	Mean	Maximum	Minimum	Standard Deviation	Source	Unit
KIN	266.1151	2155.992	-4.7614	311.8511	Authors' Computation	index
OUT	2035.682	14385.30	194.8731	2636.459	World Bank	US$
FND	0.1355	0.6426	0.0135	0.1108	IMF	Percentage
UBN	38.3325	89.3700	8.2460	15.8174	World Bank	Percentage
PTN	98.1566	623.3020	2.1798	123.7951	World Bank	Kilometer
TGE	4.8527	29.7733	0.0941	4.5376	AfDB	Percentage
QOG	-1.4844	2.1440	-4.7014	1.4612	Authors' Computation	index
FDI	4.6085	103.3374	-6.0572	1.4612	World Bank	Percentage
ODA	8.7381	92.1415	-0.2509	8.8644	World Bank	Percentage
PPI	0.0190	1.2559	3.55E-06	0.0569	World Bank	Percentage

Source: Authors' Computation
Note: KIN is infrastructure development, OUT is GDP per capita, FND is domestic financial development, UBN is urbanization, PTN is population density, TGE is total government capital expenditure, QOG is quality of governance, FDI is foreign direct investment, ODA is official direct investment and PPI is private participation in infrastructure

The descriptive statistics of the variables used in this study are presented in Table 1. The results show that the mean infrastructure index is 266.1151, with values ranging from -4.7614 to 2155.992. Negative figures indicate underdeveloped infrastructure, while large positive values represent well-developed infrastructure. The average values for other key variables are as follows: GDP per capita is $2035.682, financial development is 0.1335%, urbanization is 38.3325%, population density is 98.1566 people per square kilometer, government capital expenditure is 4.8527%, quality of governance is -1.4844 (index), PPI is 0.0190%, and ODA is

8.7381%. In terms of variability, GDP per capita shows the highest standard deviation at $2636.459, followed by infrastructure development (311.8511), population density (123.7951 km²), urbanization (15.8174%), ODA (8.8644%), and government capital expenditure (4.5376%). This indicates that GDP per capita exhibits the most variation, followed by infrastructure development, population density, and urbanization. On the other hand, PPI has the lowest variation, with a standard deviation of 0.0569%.

Table 2 Correlation Matrix

Variables	KIN	OUT	FND	UBN	PTN	TGE	QOG	FDI	ODA	PPI
KIN	1.0000									
	-									
OUT	0.8005[a]	1.0000								
	(0.0000)	-								
FND	0.6852 [a]	0.7076 [a]	1.0000							
	(0.0000)	(0.0000)	-							
UBN	0.4178 [a]	0.5880 [a]	0.3488 [a]	1.0000						
	(0.0000)	(0.0000)	(0.0000)	-						
PTN	0.3954[a]	0.1570[a]	0.1578[a]	-0.2259[a]	1.0000					
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	-					
TGE	-0.0386[a]	-0.0676[c]	-0.0360	-0.0014	-0.1507[a]	1.0000				
	(0.2699)	(0.0532)	(0.3035)	(0.9682)	(0.0000)	-				
QOG	0.5756[a]	0.5415[a]	0.6714[a]	0.2431[a]	0.2025[a]	-0.0097	1.0000			
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.7812)	-			
FDI	0.04171	0.0323	0.0262	0.1323[a]	-0.1109[a]	0.1103[a]	0.0125	1.0000		
	(0.2337)	(0.3564)	(0.4542)	(0.0001)	(0.0015)	(0.0016)	(0.7196)	-		
ODA	-0.3233[a]	-0.4267[a]	-0.3138[a]	-0.3108[a]	0.0191	-0.0233	-0.1756[a]	0.2165[a]	1.0000	
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.5852)	(0.5055)	(0.0000)	(0.0000)	-	
PPI	0.0759[b]	0.1228[a]	0.0631[c]	-0.0136	-0.0353	0.0350	0.0714[b]	0.0076	0.0598[c]	1.0000
	(0.0301)	(0.0000)	(0.0715)	(0.6983)	(0.3136)	(0.3172)	(0.0414)	(0.8273)	(0.0874)	-

Source: Authors' Computation
Note: KIN is infrastructure development, OUT is GDP per capita, FND is domestic financial development, UBN is urbanization, PTN is population density, TGE is total government capital expenditure, QOG is quality of governance, FDI is foreign direct investment, ODA is official direct investment and PPI is private participation in infrastructure. Values in the parentheses ( ) are the p-values of the test statistic, 'a', 'b', and 'c' imply significance @ 1, 5, and 10 percent

Table 2 presents the results of the correlation matrix. The findings reveal that infrastructure development is negatively correlated with ODA but shows positive correlations with GDP per capita, financial development, urbanization, population density, governance, and PPI. Notably, infrastructure development exhibits the strongest correlation with GDP per capita, with a correlation coefficient of 0.8055.

Importantly, the correlation coefficients between all the regressors are below 0.8, indicating that the models estimated in this study do not suffer from multicollinearity. This suggests that the relationships between the independent variables are not strong enough to cause estimation problems, ensuring the reliability of the regression results.

Table 3 Cross-Sectional Dependence Test

Test	Statistic	Prob.
Breusch-Pagan LM	10391.27[a]	0.0000
Pesaran scaled LM	222.2571[a]	0.0000
Pesaran CD	75.8964[a]	0.0000

Source: Authors' Computation
Note: 'a' implies significance @ 1 percent

Table 4 Panel Unit Roots Test Results

Series	Stationary	HT	ADF-Fisher	LLC	Breitung	IPS	Decision
KIN	Level	1.0511	5.2243	5.0381	18.5510	21.9601	I(1)
		(1.0000)	(1.0000)	(1.0000)	(1.0000)	(1.0000)	
	First	0.0301[a]	268.1691[a]	-5.9850[a]	-4.5571[a]	-6.4263[a]	
	difference	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
OUT	Level	0.9981	51.791	0.6712	11.9270	9.0521	I(1)
		(1.0000)	(0.999)	(0.7490)	(1.0000)	(1.0000)	
	First	0.1622[a]	404.8812[a]	-7.9210[a]	-8.5092[a]	-9.2643[a]	
	difference	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
FND	Level	0.9321	104.9871[c]	-0.4600	3.4832	5.5961	I(1)
		(0.9999)	(0.080)	(0.9231)	(1.0000)	(1.0000)	
	First	0.1412[a]	456.9321[a]	-7.4610[a]	-8.3652[a]	-10.2263[a]	
	difference	(0.0000)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	
UBN	Level	1.0031	326.6580	12.2952	21.9541	24.5500	I(1)
		(1.0000)	(0.0000)	(0.0000)	(1.0000)	(1.0000)	
	First	0.7312[a]	351.7431[a]	-2.6581[b]	10.5661	8.6091	
	difference	(0.0000)	(0.0000)	(0.0502)	(1.0000)	(1.0000)	
PTN	Level	1.0280	96.9931	-0.3011	23.3330	37.3221	I(1)
		(1.0000)	(0.1960)	(0.3812)	(1.0000)	(1.0000)	
	First	0.5341[a]	189.3982[a]	-12.3931[a]	14.8451	5.0753	
	difference	(0.0000)	(0.0001)	(0.0000)	(1.0000)	(1.0000)	
TGE	Level	0.8 692	32.4480	4.9430	10.6732	12.5181	I(1)
		(0.7881)	(1.0000)	(1.0000)	(1.0000)	(1.0000)	
	First	-0.0693[a]	587.0691[a]	-9.3371[a]	-11.0420[a]	-10.6114[a]	
	difference	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
QOG	Level	0.7780	134.661[a]	-4.1263[a]	0.2714	-1.8011[b]	I(0)
		(0.4791)	(0.0000)	(0.0000)	(0.6070)	(0.0361)	
	First	0.0452[a]	586.3090[a]	-14.0341[a]	-12.7241[a]	-12.7471[a]	
	difference	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0000)	
FDI	Level	0.4881[a]	32.4480	-2.2471[b]	-2.4963[a]	-1.2531	I(0)
		(0.0002)	(1.0000)	(0.0120)	(0.0061)	(0.1052)	
	First	-0.1532a	587.0690[a]	-9.9682[a]	-15.0081[a]	-12.4670[a]	
	difference	(0.0001)	(0.0000)	(0.0001)	(0.0000)	(0.0000)	
ODA	Level	0.4192[a]	164.6250[a]	-1.4872[c]	-1.2340	-2.3972[a]	I(0)
		(0.0000)	(0.0000)	(0.0691)	(0.1090)	(0.0081)	
	First	-0.1761[a]	888.2590[a]	-11.8843[a]	-14.3472[a]	-13.8011[a]	
	difference	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	
PPI	Level	0.6314[a]	237.4999[a]	6.8899	6.7841	9.2180	I(1)
		(0.0001)	(0.0000)	(1.0000)	(1.0000)	(1.0000)	
	First	-0.2483[a]	677.2041[a]	-5.6980[a]	-3.8899[a]	-9.2821[a]	
	difference	(0.0002)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	

Source: Authors' Computation
Note: Values in the parentheses ( ) are the p-values of the test statistic, a, b, and c imply significance @ 1, 5, and 10 percent

Table 3 presents the results of the cross-sectional dependency tests, utilizing the Pesaran and Breusch-Pagan LM tests. At the 1% significance level, the findings confirm the presence of cross-sectional dependence among the variables. This issue is exacerbated by the high degree of economic interdependence among SSA countries. Ignoring cross-sectional dependence could lead to biased and inconsistent results (Appiah et al., 2022). As previously discussed, this is one

of the key reasons for using the PCSE technique in this study, which is well-suited for addressing such issues.

Additionally, it is essential to test the panel series for stationarity or unit roots, as non-stationary data can severely affect econometric estimates. To assess the order of integration for the variables, we apply a series of panel unit root tests. Table 4 displays the results from the Harris-Tzavalis (HT), ADF-Fisher, Levin, Lin, and Chu (LLC), Breitung, and Im, Pesaran, and Shin (IPS) stationarity tests. The null hypothesis for all these tests is that the panel series contains a unit root or is non-stationary.

The results indicate that governance, FDI, and ODA are stationary at the level (integrated of order 0), while infrastructure development, GDP per capita, financial development, urbanization, population, and government capital expenditure are integrated of order 1. These findings demonstrate that there are differences in the integration order of the panel series, highlighting the importance of addressing this variation in the analysis.

Table 5 Kao-Engle-Granger Panel Cointegration Results

Test	Statistic	Prob.	Conclusion (H_0)
Modified Dickey-Fuller	2.6899[a]	0.0036	Reject
Dickey-Fuller	2.8535[a]	0.0022	Reject
Augmented Dickey-Fuller	2.3660[a]	0.0090	Reject
Unadjusted Modified Dickey-Fuller	3.0932[a]	0.0010	Reject
Unadjusted Dickey-Fuller	3.3279[a]	0.0004	Reject

Source: Authors' Computation
Note: H_0: No cointegration, a implies significance @ 1 percent and H_0 is rejected

Following the unit root tests, the cointegration test is conducted to examine the long-term relationships between the variables. Table 5 presents the results of the long-term cointegration analysis using the Kao-Engle Granger test. This method is chosen due to its ability to accommodate a greater number of regressors compared to the more constrained Pedroni and Westerlund cointegration tests. The results from the Kao cointegration test indicate that all panel series are cointegrated, as evidenced by statistically significant results at the 1% level across all test statistics. This confirms the existence of a stable long-term relationship among the variables in the model.

4.2. PCSE Long-run Effects

The key findings from Equations (1) to (4), (5) to (8), and (9) to (12) for the estimations of infrastructure development, physical infrastructure, and social infrastructure models are presented in Table 6. Importantly, the results of several statistical tests demonstrate the robustness of the estimates produced by the PCSE models. The variance inflation factor (VIF) values for the infrastructure development, physical infrastructure, and social infrastructure models are 2.04, 1.52, and 1.52, respectively. These low VIF values suggest that multicollinearity among the explanatory variables is not a significant issue, a conclusion further supported by the correlation analysis results.

Additionally, the Wald Chi-square statistics, all of which are significant at the 1% level, along with the R^2 statistics, ranging from 0.750 to 0.617, indicate that the model estimations are both reliable and appropriate for decision-making. The high significance of the Wald Chi-square values affirms the overall goodness-of-fit of the models, while the R^2 values suggest a strong explanatory power of the independent variables in predicting infrastructure development outcomes.

4.2.1. Direct Effects of External Financing Factors

Table 6 provides evidence regarding the effects of external financing factors on infrastructure development and its components. The results show that the coefficients for private participation in infrastructure (PPI) are negative and statistically insignificant for both overall infrastructure development and its components. Conversely, the coefficients for ODA are negative but statistically significant at the 1% level for infrastructure development and its components.

The coefficients for FDI are positive and statistically significant at the 5% level for infrastructure development and physical infrastructure, but negative and statistically insignificant for social infrastructure. This suggests that FDI positively influences both infrastructure development and physical infrastructure, but has no significant effect on social infrastructure. Additionally, ODA appears to negatively impact infrastructure development and its components.

In practical terms, a 1% increase in FDI leads to a 1.740% increase in overall infrastructure development and a 2.359% increase in physical infrastructure. Conversely, a 1% reduction in ODA results in increases of 2.008%, 2.550%, and 0.157% in physical infrastructure, social infrastructure, and overall infrastructure development, respectively.

The beneficial linkage of FDI to infrastructure development and physical infrastructure may stem from the fact that FDI provides these countries with technology and capital that they may not otherwise have, allowing them to construct and modernize infrastructure like energy, telecommunications, and transportation. It frequently includes knowledge and best practices for project management that raise the efficacy and efficiency of the work. Additionally, FDI has the potential to stimulate economic growth, creating opportunities for increased infrastructure investment and supporting the long-term development of SSA nations. These findings align with Shinwari et al. (2024), who argued that FDI, accompanied by innovative technologies and advanced expertise, exerts a greater influence on infrastructure development compared to domestic investments. FDI is particularly effective in introducing new technologies or addressing infrastructure demands through adaptive strategies. However, this contrasts with the conclusions of Appiah et al. (2022), who observed that FDI negatively affects infrastructure development in SSA. In SSA, foreign investments are often concentrated on resource extraction rather than infrastructure improvement, which could explain why FDI has a limited impact on social infrastructure. Similarly, PPI appears to lack a direct effect on infrastructure growth or its components.

The adverse effects of ODA on infrastructure development and its components in SSA can be attributed to multiple factors. One issue is that excessive reliance on aid can reduce government ownership and accountability, leading to inefficiencies and poor resource management in infrastructure projects. Moreover, ODA flows are frequently inconsistent and unpredictable, complicating efforts to plan and execute long-term infrastructure initiatives effectively. Donor countries may also use tied aid to advance their interests, which can result in funding projects that are either misaligned with local development priorities or unsustainable over time. Dependence on ODA may additionally weaken domestic resource mobilization and discourage private sector investment, further limiting SSA countries' capacity to establish self-sufficient infrastructure systems. These findings are consistent with earlier research, which has highlighted that the advantages of ODA for recipient countries are often complex and not guaranteed (Nam & Ryu, 2023; Wang & Zhuang, 2021). This suggests that while ODA can provide short-term relief, it may not create the conditions necessary for achieving sustainable infrastructure development over the long term.

The Two-Gap theory, which emphasizes the importance of external financing in facilitating the transfer of technology, capital, and managerial expertise to developing nations, supports the theoretical rationale for the positive and statistically significant impact of FDI on infrastructure

development and physical infrastructure. However, the results concerning ODA and PPI cast doubt on the overall advantages of external financing for recipient countries. These results are consistent with theories and empirical studies that criticize aid dependency, suggesting that over-reliance on ODA and PPI can lead to inefficiencies, mismanagement, and the erosion of local responsibility and governance. This underscores the importance of fostering domestic capacity and accountability to ensure that external financing contributes to sustainable infrastructure development.

4.2.2. Indirect Effects of External Financing Factors

Based on the infrastructure development models in Table 6, the coefficient estimates reveal significant positive impacts of governance and external financing factors (PPI, ODA, and FDI) on infrastructure development and its components. However, the interaction between governance and PPI does not significantly affect social infrastructure. The findings show that an increase in the interaction between governance and PPI boosts infrastructure development and physical infrastructure in SSA countries by 7.7946% and 10.065%, respectively. Additionally, increases in the interaction between governance and ODA lead to growth in infrastructure development, physical infrastructure, and social infrastructure by 0.868%, 1.091%, and 0.083%, respectively. Moreover, infrastructure development, physical infrastructure, and social infrastructure rise by 0.537%, 0.658%, and 0.067%, respectively, in response to the interaction between FDI and governance.

These results affirm the crucial role of governance in facilitating infrastructure development in SSA countries. Consequently, the findings support the hypothesis and theories suggesting that governance strengthens the positive impact of external financing inflows on infrastructure development in SSA. While enhancing PPI alone may only marginally improve infrastructure development, fostering good governance amplifies this effect. Similarly, Appiah et al. (2024) report that the interaction between institutional quality measures and governance indicators significantly promotes infrastructure development in SSA countries. These findings align with those of Ali & Bhuiyan (2022), who emphasize the importance of governance quality for the development of physical infrastructure.

Theoretically, the moderating role of governance in strengthening the effects of infrastructure development's external financing highlights the critical importance of good governance. These findings further support the Two-Gap theory, which asserts that good governance enhances the influence of external financing on infrastructure development and its components.

To further corroborate the PCSE estimates, this study also employs the System Generalized Method of Moments (SGMM) for robustness. SGMM is chosen for its ability to address endogeneity issues, allowing for a greater number of moment conditions and accommodating complex data structures. It is particularly efficient in dynamic panel data models, providing more accurate parameter estimates. The results from the SGMM are presented in the appendices for brevity.

Table 6 Results of the PCSE Long-run Effects

Explanatory Variables	Infrastructure Development				Physical Infrastructure				Social Infrastructure			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
OUT	0.070[a]	0.075[a]	0.078[a]	0.080[a]	0.092[a]	0.098[a]	0.102[a]	0.104[a]	0.003[a]	0.004[a]	0.004[a]	0.004[a]
	(16.65)	(20.12)	(19.56)	(21.83)	(16.21)	(19.41)	(18.90)	(21.04)	(23.87)	(39.88)	(42.15)	(48.91)
TGE	-0.005[b]	-0.006[a]	-0.007[b]	-0.006[b]	-0.006[b]	-0.007[b]	-0.008[b]	-0.007[b]	-0.001[a]	-0.001[a]	-0.001[a]	-0.001[a]
	(-2.594)	(-2.822)	(-2.606)	(-2.350)	(-2.182)	(-2.499)	(-2.292)	(-2.041)	(-10.58)	(-9.765)	(-10.23)	(-10.67)
FND	0.892[a]	0.880[a]	1.088[a]	1.045[a]	1.161[a]	1.146[a]	1.414[a]	1.361[a]	0.047[a]	0.045[a]	0.059[a]	0.055[a]
	(4.915)	(5.764)	(5.466)	(5.535)	(4.845)	(5.700)	(5.381)	(5.453)	(5.347)	(5.224)	(7.285)	(7.286)
PTN	0.702[a]	0.670[a]	0.712[a]	0.701[a]	0.904[a]	0.861[a]	0.917[a]	0.903[a]	0.046[a]	0.046[a]	0.047[a]	0.046[a]

Explanatory Variables	Infrastructure Development				Physical Infrastructure				Social Infrastructure			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	(21.67)	(22.77)	(21.56)	(19.85)	(21.26)	(22.22)	(21.11)	(19.31)	(11.35)	(12.34)	(11.71)	(12.70)
UBN	1.175[a]	1.032[a]	1.123[a]	1.290[a]	1.173[a]	0.983[a]	1.115[a]	1.321[a]	0.445[a]	0.442[a]	0.432[a]	0.451[a]
	(5.072)	(4.032)	(3.618)	(4.617)	(3.682)	(2.804)	(2.650)	(3.467)	(26.91)	(24.63)	(28.89)	(30.55)
QOG	27.01[a]				34.84[a]				1.767[a]			
	(9.623)				(9.081)				(8.359)			
PPI	-1.805				-2.406				-0.128			
	(-0.163)				(-0.164)				(-0.174)			
ODA	-2.008[a]				-2.550[a]				-0.157[a]			
	(-3.434)				(-3.253)				(-2.673)			
FDI	1.740[b]				2.359[b]				-0.003			
	(2.311)				(2.333)				(-0.079)			
QOGPPI		7.946[c]				10.065[c]				0.707		
		(1.850)				(1.821)				(1.602)		
QOGODA			0.868[c]				1.091[b]				0.083[a]	
			(1.850)				(3.156)				(4.411)	
QOGFDI				0.537[c]				0.658[c]				0.067[a]
				(1.854)				(1.757)				(2.672)
Constant	37.96[c]	22.19[c]	-16.84	-35.48	41.13	23.61	-29.46	-52.93[b]	8.085[a]	4.100[b]	4.524[a]	2.806[b]
	(1.715)	(1.118)	(-0.875)	(-2.155)	(1.364)	(0.868)	(-1.128)	(-2.353)	(5.880)	(3.147)	(4.287)	(2.909)
Wald x^2– statistic	22773.25 [0.000]	15301.04 [0.000]	21057.30 [0.000]	20433.55 [0.000]	19871.85 [0.000]	12944.60 [0.000]	19147.99 [0.000]	18232.16 [0.000]	6901.03 [0.000]	4468.87 [0.000]	3653.49 [0.000]	4042.83 [0.000]
Multicollinearity (VIF)	2.04				1.52				1.52			
R-squared	0.750	0.750	0.740	0.737	0.732	0.733	0.722	0.720	0.626	0.616	0.620	0.617
Number of Countries	43	43	43	43	43	43	43	43	43	43	43	43
Observation	817	817	817	817	817	817	817	817	817	817	817	817

Source: Authors' Computation
Note: Values in the parentheses ( ) are the p-values of the test statistic, a, b, and c imply significance @ 1, 5, and 10 percent

In addition to the main variable of interest, the estimates in Table 6 indicates that all the control variables—GDP per capita, governance, financial development, population density, and urbanization—positively impact infrastructure development and its components, with the exception of government capital expenditure, which shows a negative effect. These factors contribute to infrastructure development in SSA countries by fostering economic growth, improving governance, advancing financial development, and increasing urbanization and population density. However, contrary to expectations, an increase in government capital expenditure appears to hinder infrastructure development, likely due to inefficient allocation of funds, corruption, and waste, which may divert resources away from essential infrastructure projects. The positive influence of GDP per capita, governance, financial development, population density, and urbanization aligns with theoretical expectations and findings from previous studies (Berawi et al., 2023; Noah, 2021; Waqar et al., 2020), while the negative effect of government capital expenditure contradicts these expectations and prior research. Theoretically, GDP per capita plays a crucial role in infrastructure development, underscoring the importance of economic growth in building and maintaining essential infrastructure. This finding supports the accelerator theory, which emphasizes the relationship between real investment, such as infrastructure, and output levels.

As Lu and Wilson (2024) noted, relying solely on government funding may be insufficient to meet the vast infrastructure needs of SSA nations, particularly given the competing demands on limited resources. Additionally, the long-term benefits of government capital expenditures can be undermined by poor maintenance and inadequate sustainability planning for infrastructure assets, leading to their deterioration over time (World Bank, 2024). Moreover, financing capital expenditures through borrowing can increase debt burdens and create fiscal vulnerabilities,

potentially constraining future infrastructure investments and limiting the economic growth potential of SSA countries.

To ensure the robustness of the PCSE estimations for external financing factors, the SGMM results were also analyzed. These finding complement the conclusions, revealing that only FDI has a direct effect on infrastructure development and its components. Furthermore, ODA does not directly influence infrastructure development or its components, while PPI only affects social infrastructure. The analysis of the moderating effect of governance quality shows that governance amplifies the impact of external financing variables on infrastructure development and its components, except for the influence of ODA on infrastructure development and physical infrastructure. Notably, post-estimation tests confirm the robustness of the estimates. The SGMM results show that there is no second-order serial correlation, and the validity of the instruments used is confirmed by the Sargan test confirms, thus passing all diagnostic tests.

5. CONCLUSION

This study empirically examines the impact of external financing sources and governance on infrastructure development in 43 SSA economies between 2000 and 2022, offering new contributions to the existing literature. It explores how external financing factors influence both physical and social infrastructure development, as well as the role of governance in moderating these effects. Furthermore, the study explores how governance interacts with external financing sources to shape infrastructure growth in SSA nations. Employing PCSE and SGMM methodologies, the findings indicate that FDI is the only external financing source that directly and positively impacts overall infrastructure development and physical infrastructure, though it does not significantly influence social infrastructure. In contrast, ODA negatively affects infrastructure development and its components, while PPI shows no direct impact. These outcomes suggest that reliance on ODA could impede infrastructure progress in SSA, highlighting the critical role of governance and FDI in driving infrastructure growth.

The results regarding the indirect effects of external financing factors on infrastructure development through governance are consistent across different types of external financing. All external financing factors indirectly contribute positively to infrastructure development. Similarly, they positively influence both physical and social infrastructure, with the exception of PPI, which does not impact social infrastructure. These findings underscore the critical role of governance as a mediating factor in enhancing the impact of external financing on infrastructure development in SSA countries. Moreover, the results show that control variables such as GDP per capita, governance, financial development, population density, and urbanization positively affect infrastructure development and its components, while government capital expenditure has a negative effect. This highlights the importance of these variables as key determinants of infrastructure growth in SSA countries and suggests potential inefficiencies in public spending.

Based on the study's findings, policymakers are encouraged to prioritize attracting foreign investment for infrastructure projects, with particular attention to physical infrastructure. Policies should focus on improving transparency, accountability, and regulatory frameworks to ensure the efficient use of foreign investments. Efforts should also prioritize attracting and optimizing FDI, while ODA should be strategically leveraged for comprehensive infrastructure projects. Given the limited impact of PPI on social infrastructure, alternative financing models should be explored for these projects. Emphasizing governance reforms will enhance the positive effects of external financing on both physical and social infrastructure, contributing to sustainable development in the region. Additionally, improving project prioritization, budgeting procedures, and governance reforms will increase the efficacy and efficiency of public spending. In infrastructure planning authorities should consider the significant contributions of factors like population density,

urbanization, financial development, governance, and GDP per capita to infrastructure development. These factors should guide decision-making and help prioritize infrastructure investments that align with broader development goals.

Future research can break down FDI into specific industries or investment categories to determine which contribute most significantly to infrastructure development within the framework of external financing factors. Additional studies could also investigate the underlying causes of ODA's negative effects, such as inefficiencies, fund misallocation, or dependency challenges, to develop more precise policy recommendations for optimizing its utilization. Moreover, to identify the most effective approaches for advancing infrastructure, particularly social infrastructure, future studies should explore various forms of private sector participation in infrastructure projects. Research should also examine how individual governance indicators interact with external financing sources to influence infrastructure development, as this study employed a composite governance quality index. Such analyses could help refine governance strategies to maximize the benefits of external financing. Since this research focuses on SSA, future studies could include comparative analyses with other regions to provide broader insights.

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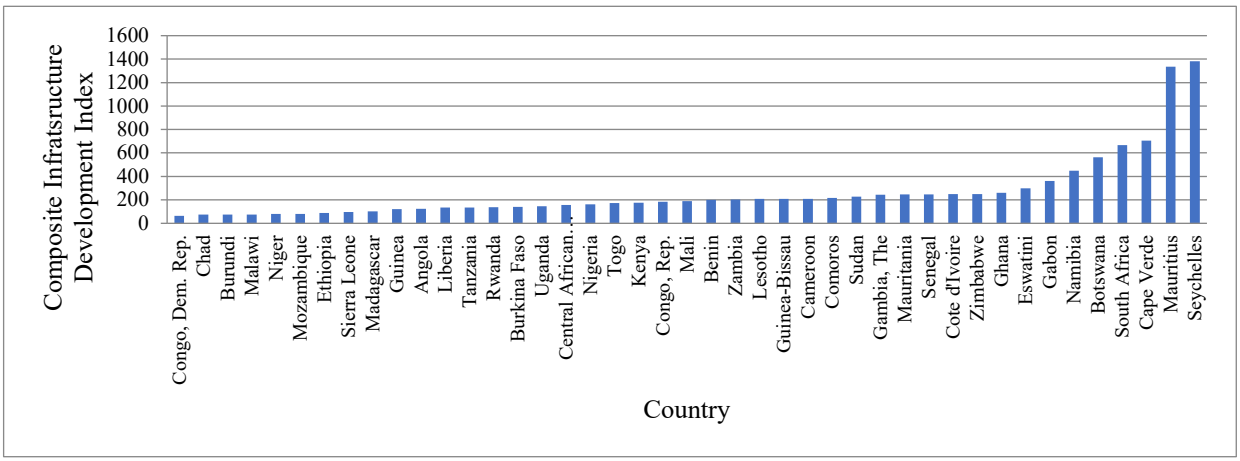
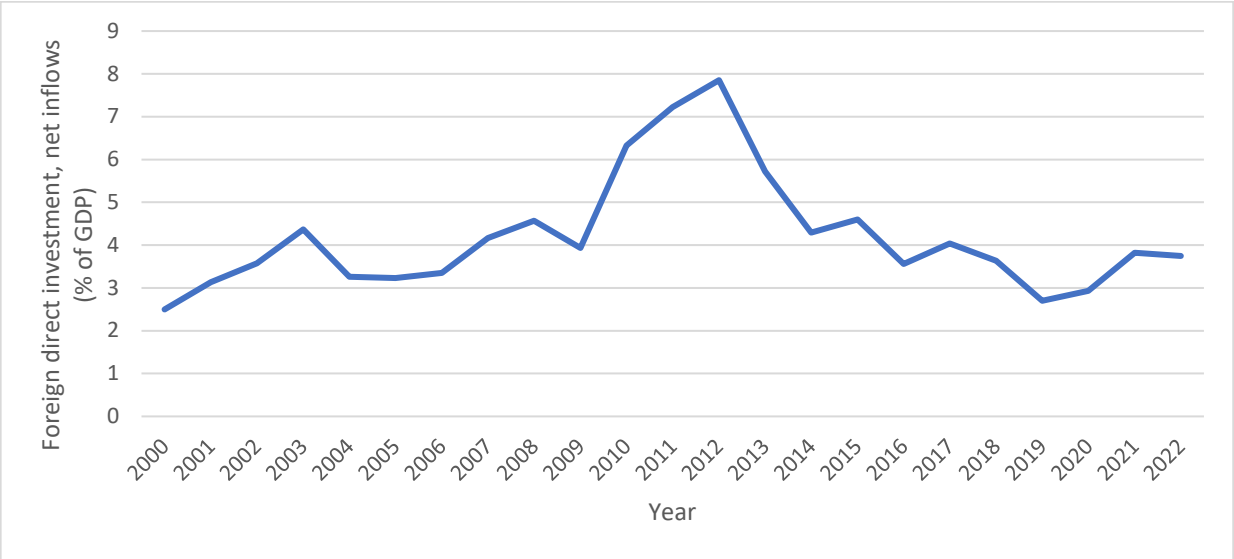
Appendices:



Appendix 1 Aggregate Trend of Infrastructure Development in the SSA Region from 2000 – 2022
(Source: Authors' computation and analysis of data)



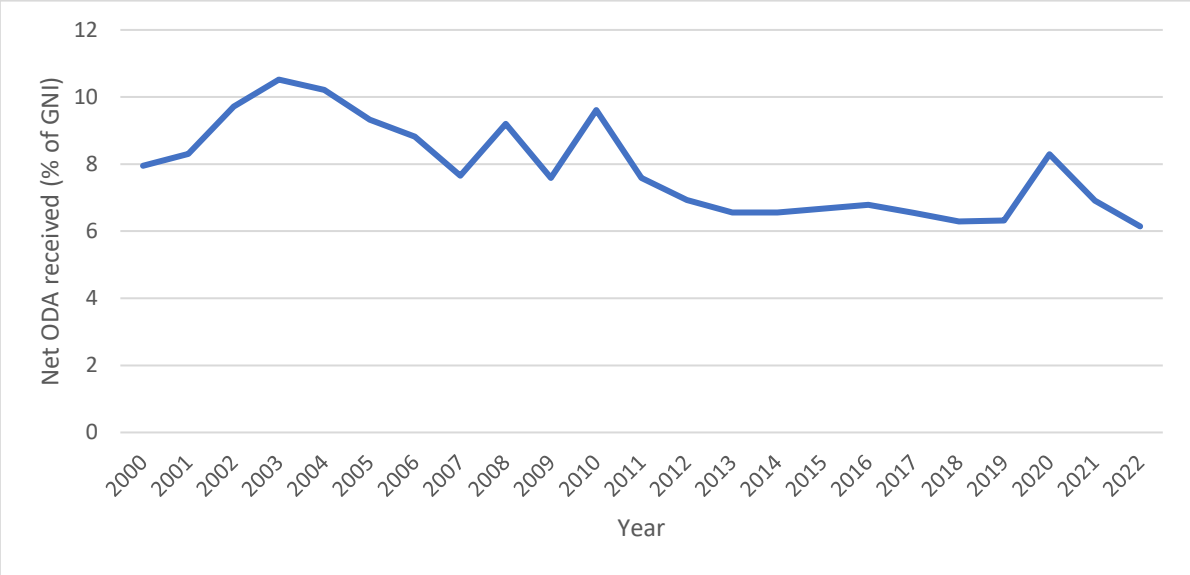
Appendix 2 Average Trend of FDI in SSA
(Source: Authors' computation and analysis of data)

Table 7 Results of the SGMM Estimates

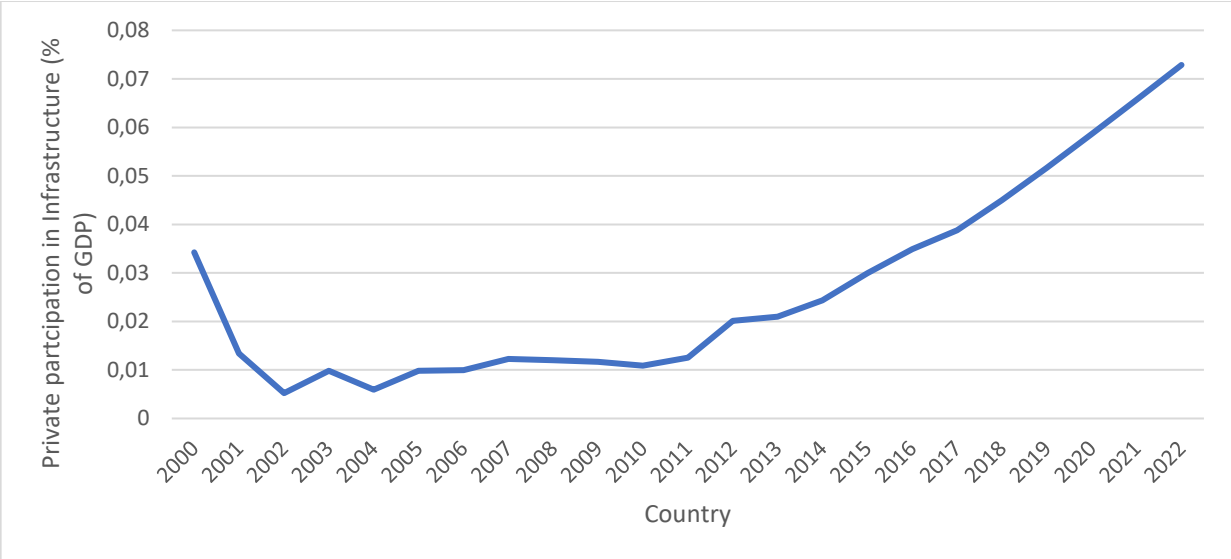
Variables	Infrastructure Development				Physical Infrastructure				Social Infrastructure			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
OUT	0.039[a]	0.039[a]	0.007[a]	0.007[a]	0.055[a]	0.055[a]	0.009[a]	0.009[a]	0.001[a]	0.001[a]	0.001[a]	0.001
	(9.796)	(63.71)	(3.626)	(31.42)	(10.10)	(13.69)	(3.569)	(53.43)	(5.813)	(5.328)	(1.484)	(3.853)
TGE	0.001	0.002	0.001	0.001[a]	0.001	0.001[b]	0.001	0.001[a]	0.001[b]	9.16e-05[b]	0.001[a]	0.001[a]
	(0.616)	(1.113)	(1.237)	(6.561)	(0.579)	(2.024)	(1.133)	(9.151)	(2.325)	(2.040)	(3.504)	(6.518)
FND	0.110	0.085[a]	0.133[b]	0.126[a]	0.155[c]	0.135[a]	0.187[b]	0.170[a]	0.007	0.008[a]	0.0237[a]	0.0228[a]
	(1.663)	(8.660)	(2.071)	(12.49)	(1.769)	(15.16)	(2.169)	(12.21)	(1.590)	(8.779)	(5.592)	(12.34)
PTN	0.063	-0.153	-0.026	-0.023	0.112	-0.009	-0.044	-0.033[c]	-0.019[a]	-0.014[a]	-0.084[a]	-0.083[a]
	(0.825)	(-1.069)	(-0.732)	(-1.103)	(1.085)	(-0.104)	(-0.928)	(-1.856)	(-3.712)	(-4.847)	(-32.26)	(-23.55)
UBN	2.552[a]	3.143[a]	0.057	-0.039	3.443[a]	3.267[a]	0.084	-0.017	-0.038	-0.090[a]	0.082[a]	0.085[a]
	(3.953)	(4.398)	(0.159)	(-0.266)	(4.013)	(6.797)	(0.176)	(-0.147)	(-1.009)	(-2.532)	(2.932)	(5.723)
QOG	-4.102				-6.915				0.999[a]			
	(-0.945)				(-1.191)				(3.791)			
PPI	-80.34				-107.6				5.929[b]			
	(-1.699)				(-1.675)				(2.050)			
ODA	0.041				0.0403				-0.002			
	(0.224)				(0.166)				(-0.200)			
FDI	0.436[a]				0.578[a]				0.015[c]			
	(3.142)				(3.104)				(1.778)			
QOGPPI		0.740[b]				0.606[b]				0.070[a]		
		(2.204)				(2.148)				(3.523)		
QOGODA			0.043				0.054				0.009[b]	
			(0.593)				(0.545)				(2.254)	
QOGFDI				0.090[a]				0.121[a]				0.005[a]
				(5.788)				(6.754)				(6.355)
L.KIN	0.882[a]	0.886[a]	1.018[a]	1.019[a]								
	(45.35)	(51.66)	(10.69)	(52.31)								
L.PIN					0.876[a]	0.880[a]	1.020[a]	1.021[a]				
					(44.95)	(33.62)	(11.07)	(8.59)				
L. SIN									0.868[a]	0.877[a]	0.913[a]	0.910[a]
									(10.07)	(12.78)	(14.15)	(11.32)
Constant	-136.9[a]	-129.2[a]	3.060	5.494	-194.9[a]	-161.9[a]	5.522	7.231[c]	11.29[a]	9.953[a]	7.577[a]	6.473[a]
	(-5.282)	(-9.992)	(0.260)	(1.513)	(-5.537)	(-11.95)	(0.359)	(1.795)	(11.09)	(8.37)	(11.06)	(9.44)
AR(2)	0.980				0.980				-0.775			
	[0.327]				[0.327]				[0.438]			
Sagan test	39.098				38.668				36.9499			
Wald x^2–statistic	12572.13				33602.44				13462.05			
	[0.000]				[0.000]				[0.000]			

Source: Authors' Computation

Note: Figures between ( ) and [ ] are z-statistic and probability values respectively. a, b, and c imply significance @ 1, 5, and 10 percent respectively. L.KIN, L.PIN, and L.SIN are the first lag of infrastructure development, physical, and social infrastructure.



Appendix 3 Average Trend of ODA in SSA
(Source: Authors' computation and analysis of data)



Appendix 4 Average Trend of PPI in SSA
(Source: Authors' computation and analysis of data)

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ASSESSMENT OF PROJECT RISK PERFORMANCE OF SELECTED MASS HOUSING INFRASTRUCTURES IN NORTHERN NIGERIA

Chinedu Chimdi Adindu[1], Abdulhaqq Onoruoyiza Muhammed[1*], Emmanuel Ashem Egila[1], and Musa Mohammed[1]

[1]*Departement of Project Management Technology, Federal University of Technology, Minna, Nigeria*

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ABSTRACT

Mass housing projects in Northern Nigeria often suffer from insufficient risk management, impacting timely delivery, budget adherence, and quality standards. This study assesses risk vulnerabilities in selected mass housing infrastructure projects, focusing on information risks related to roles, responsibilities, scope, requirements, and operations. A mixed-methods approach was employed, with data collected from 465 construction professionals across 20 states, with a 64.58% response rate. Analytical tools, including regression and Pearson correlation, identified critical risks such as underfunding, weak project monitoring and control, and the failure to deliver end-user value. Findings reveal that these risks significantly undermine project outcomes, highlighting the need for robust risk management strategies. A risk management framework is proposed to prioritize and address these vulnerabilities throughout the project lifecycle. This research contributes to the field by offering actionable insights for policymakers and practitioners to enhance mass housing delivery, ensuring alignment with end-user needs and project goals.

Keywords: Assessment; Mass housing infrastructure; Northern Nigeria; Risk Performance

1. INTRODUCTION

The housing deficit in Nigeria has reached critical levels over the past three decades. Literature highlights a deficit of 12 million units in 2007, 14 million units in 2010, 20 million units in 2018, and an estimated 28 million units in 2023 (Oshundairo, 2023). Recent decades have also seen a global surge in real estate investments by individuals, corporate organizations, and governments alike (Nabawy et al., 2021). This increase in mass housing projects is driven by the need to meet the growing demand for shelter due to unprecedented migration, urbanization, and population growth (Sdino et al., 2018). Real estate development projects are inherently unique; no two projects are exactly alike, as they differ in legal, commercial, administrative, technical, and physical aspects (Kalgo et al., 2019; Shittu et al., 2022). The inherent complexity of such projects heightens their vulnerability to risks, which compromise delivery timelines, budgets, and quality standards (Kloppenberg, 2012; Ayudhya et al., 2019). Despite growing investments in mass housing, both globally and in Nigeria, many projects fail to meet the needs of beneficiaries. Factors such as insufficient risk assessments, weak project monitoring, underfunding, and inadequate stakeholder involvement exacerbate these challenges. For instance, Sdino et al. (2018) note that financialization and economic volatility have amplified risks in real estate investments. In Nigeria, mass housing schemes are particularly susceptible to risks due to unstable socio-political conditions and insufficient integration of end-user requirements during the planning and

*Corresponding author's email: mhhaqq@gmail.com

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execution phases (Shittu et al., 2022; Topal et al., 2018; Karji et al., 2019).

In the construction industry, project execution involves a production matrix that creates deadlines and logistical constraints, requiring project resources to work together to meet pre-determined objectives (Jegede et al., 2021). While it is nearly impossible to eliminate all risks in housing projects, they can be minimized by adopting proactive strategies to manage the frequency and impact of potential risks (Arijeloye, 2021). Conceptually, a risk is any factor that may hinder a project team's ability to achieve success and meet stakeholder priorities (Kloppenberg, 2012). In Nigeria, this critical risk management process is often absent in mass housing projects, necessitating an assessment of project teams' performance in managing information risks—particularly those related to roles and responsibilities, scope and requirements, and operations of mass housing infrastructure projects.

The ability to manage key project risks, particularly those related to finance and logistics, is essential to achieving success across the housing delivery chain (Crane et al., 2013). Unfortunately, many mass housing programs in Nigeria are conducted without adequate risk vulnerability assessments, particularly in terms of risk information sourcing (Taghizadeh-Hesary & Yoshino, 2020), identification (Siraj & Fayek, 2019), planning (Young, 2020), monitoring, and control (Chan & Aghimien, 2020). Many stakeholders tend to overlook or downplay these crucial processes, which in turn impacts the overall performance of mass housing schemes with respect to completion timelines (Del Pero et al., 2021), budgeted costs (Chan & Aghimien, 2020), and prescribed quality standards (Del Pero et al., 2021). Consequently, many mass housing projects fail to meet the needs of their intended beneficiaries, becoming vulnerable to various operational risks at post-contract stages (El-Sayegh et al., 2021).

This study seeks to address this gap by conducting the Risk Vulnerabilities Assessment (RVA) to the mass housing infrastructure projects in Northern Nigeria, given the growing need for project teams to assess information risks related to roles and responsibilities, scope and requirements, and operations. Specifically, it focuses on three critical dimensions of project risk information: roles and responsibilities, scope and requirements, and operations. By identifying the most significant risks affecting project performance, the study aims to develop a risk management framework to enhance the success of mass housing projects in the region. The primiary objectives of this study are: 1) to determine the extent to which project teams assess information risks related to roles and responsibilities in mass housing infrastructure projects; 2) to determine the extent to which project teams assess information risks related to scope and requirements in mass housing infrastructure projects; and 3) to determine the extent to which project teams assess information risks related to operations in mass housing infrastructure projects.

2. LITERATURE STUDY

2.1. The Concept of Project Risks

The construction industry is widely recognized as one of the most risk-prone sectors globally (Sheen et al., 2017). Risk refers to potential events that could derail project plans, and accounting

for every possible risk in construction projects is a challenging task (Hazem, 2021). Sheen et al. (2017) define risk as “the presence of potential or actual constraints that could hinder project performance, causing partial or complete failure during construction or at the time of use.” The concept of risk is often better understood through a connection to physics, specifically Newtonian theories. The term "risk" originates from the French word "risqué" (Roberts et al., 2012). Risk is also closely associated with the concept of uncertainty, which extends from the Newtonian to the Heisenbergian paradigm in economics.

Historically, risk has been closely linked to uncertainty, a concept rooted in Newtonian physics and later extended to economics under the Heisenbergian paradigm (Roberts et al., 2012). The term “risk” originates from the French word risqué, emphasizing its early association with unfavorable events requiring identification, measurement, and mitigation. Initially, risk was viewed as measurable uncertainty, contrasting with broader ignorance about unpredictable future events. According to Roberts et al. (2012), risks are best understood when organizational objectives are clearly defined, as structured analysis and adjustments can improve the likelihood of achieving success.

Crane et al. (2013) emphasize the importance of setting risk management goals, which reflect organizational priorities, stakeholder values, and resource capabilities. Risks in construction projects can emerge from diverse sources, including technical, financial, environmental, legal, and political factors, as well as force majeure events (Kloppenborg, 2012; Fergany et al., 2019). Common technical risks include skill shortages (Taghizadeh-Hesary & Yoshino, 2020), delays in design approvals (Ogunsanmi, 2016), equipment shortages (Khodeir & Nabawy, 2019), and rising construction costs (Muhammed et al., 2022). Other risks involve poor safety practices leading to site accidents (Abd-Eltawab et al., 2018), differing site conditions (Abdallah et al., 2019), bureaucratic delays (Ogunsanmi, 2016), and adverse weather conditions (Kishan et al., 2014). The variety and complexity of risks make classification and management particularly challenging (Roberts et al., 2012).

Sdino et al. (2018) categorize risks into market risks, which are inherent to industry activities and difficult to diversify, and specific risks, which arise from particular project actions (Shao et al., 2015). Effective risk management strategies are critical, as risks and uncertainties, though conceptually distinct, are often intertwined and equally disruptive (Adindu, 2015). Qualitative risk assessments evaluate the likelihood of an event impacting a project relationship, while quantitative assessments focus on economic or financial outcomes.

Sheen et al. (2017) note that risks exist on a spectrum: certain events occur with a 100% probability, while entirely uncertain events have a probability of 0%. While risks are inherently rooted in uncertainty, the two cannot be entirely eliminated. Therefore, mitigating risks and minimizing their impact require rational, systematic strategies. Cooper et al. (2005) propose three core strategies for managing project risks: early identification and analysis, systematic planning of mitigation measures, and assigning responsibility to the most capable party. These strategies may involve adopting new practices, implementing effective systems, negotiating contracts, and ensuring that risk mitigation costs align with the project's importance.

Abhinaya and Nidhu (2017) define risk management as a systematic process that involves identifying, analyzing, and responding to risks that could derail planned objectives. By integrating these strategies into project processes, organizations can proactively address risks and improve their likelihood of success.

2.2. Risk Performance Assessment

Hazem (2021) posits that construction risks can best be effectively minimized when stakeholders anticipate and prepare for potential setbacks from project conception through to completion. The dynamic and intricate nature of the construction industry often creates high levels of uncertainty, which increase exposure to risks (Sheen et al., 2017). Risk performance assessment focuses on evaluating the extent to which a project, product, or service delivers its intended value. Performance risk is prevalent across different project types, including internal initiatives, outsourced projects, and procurement activities, where failure to meet expectations signals varying degrees of risk. Liu and Yetton (2006) emphasize that project underperformance often results in avoidable yet significant economic losses. A key impediment to achieving planned outcomes is the lack of executive management support, as noted by Khalili-Araghi and Kolarevic (2016) and Zarewa (2019). Additionally, Wackers et al. (2016) highlight that assessing the future behavior of systems helps prevent inefficiencies that reduce operational performance.

Abhinaya & Priscil (2017) identify several causes of risk management failure, including scope limitations, lack of top management support, non-inclusiveness of all stakeholders, poor information dissemination, and the failure to incorporate risk management within organizational systems. Project Information Risks Analysis (PIRA) is essential in determining how each risk information factor contributes to an enterprise's overall economic result. This information is crucial for identifying risks along the production process and assessing their impact on business operations, particularly in terms of supply chain disruption (Borghesi & Gauglenzi, 2013). The process involves conducting a tactical vulnerability analysis of identified project information risk factors.

Several types of information vulnerability risks are typical in a production process, including: human vulnerability (arising from individuals or organizations), operational vulnerability (disruption to supplies, operations, access to essential assets, distribution failures, etc.), reputational vulnerability (loss of business partner or employee confidence, damage to market reputation etc.), procedural vulnerability (failures in accountability, internal systems, controls, fraud, etc.), project vulnerability (risks of cost overruns, time delays, insufficient product or service quality, etc.), financial vulnerability (business failure, stock market fluctuations, interest rates, unemployment, etc.), technical vulnerability (advances in technology, technical failures, etc.), natural vulnerability (threats from weather, natural disasters, accidents, disease, etc.), and political vulnerability (changes in tax regimes, public opinion, government policy, foreign influence, etc.) (Borghesi & Gauglenzi, 2013).

To systematically evaluate and address these vulnerabilities, Risk Vulnerability Analysis (RVA) is conducted using a standardized template. This template identifies key corporate assets, potential hazards, and corresponding vulnerabilities. Abhinaya and Priscil (2017) propose the inclusion of critical components such as risk descriptions, current control measures, and risk impact ratings. The impact and likelihood of risks are assessed on a scale of 1 to 5, where 1 represents the least severity or likelihood and 5 indicates catastrophic impact or unavoidable occurrence.

Liu and Yetton (2006) provide a quantitative approach to measuring risks through risk exposure (RE):

$$RE = Probability\ of\ unsatisfactory\ outcome\ \times\ Potential\ loss$$

Additionally, mitigation measures are evaluated using the Risk Reduction Leverage (RRL) formula:

$$RRL = \frac{RE_{before} - RE_{after}}{Cost\ of\ intervention}$$

Pemberton et al. (2016) emphasize that risk assessments enhance project management by promoting informed decision-making and optimal resource allocation. In sectors like environmental construction, risk assessments are even legally mandated, as in the case of Environmental Impact Assessments (EIA). Such processes reduce waste and ensure efficiency, particularly in large-scale infrastructure projects.

The principles of Project Information Risk Analysis (PIRA) form the foundation for this study, as they allow empirical examination of risk factors' contributions to project outcomes. The decision rule is that the higher the Relative Vulnerability Index (RVI), the greater the likelihood of failure in performance (RFP), indicating the criticality of the risk factor.

This study follows the approach adopted by Fergany et al. (2019), who developed a "risk assessment model for residential construction projects" using the Relative Importance Index (RII) method, adapted from Sheen et al. (2017). The results from this study will serve as a valuable resource for mass housing project stakeholders. By identifying patterns of risk vulnerabilities, stakeholders can implement strategies for risk planning, monitoring, control, and mitigation to improve project performance.

2.3. Risk Assessment and Project Success

Risk management is essential for addressing uncertainties to achieve project success while mitigating prolonged litigation, loss of revenue, delays, and reputational damage. Globally, construction projects are inherently high-risk, often experiencing cost overruns and schedule delays, particularly in developing countries. These challenges are further aggravated by economic instability and institutional weaknesses. In many developing nations, construction contracts are frequently awarded to indigenous contractors with limited expertise, increasing exposure to project risks. Ogbu and Adindu (2019) observed a significant positive correlation between aggregate project risk, the project risk index of cost (PRIC), and cost performance in construction projects.

The need for global competitiveness and shrinking profit margins has compelled businesses to adopt structured risk management strategies to optimize returns on assets and equity. However, growth objectives are often hindered by financial and operational risks. For example, Stan-Maduka (2010) emphasizes that organizations must address such risks to achieve sustainable growth. Ogbu and Adindu (2019) further identify critical factors influencing risk management strategies, including organizational mission and goals, product and service offerings, management style, organizational practices, and physical, regulatory, and environmental conditions.

Risk theory categorizes risks as internal, systemic, or external, forming the foundation for an organization's risk management strategy, particularly regarding environmental challenges (Borghesi & Gaudenz, 2013). Internal risks arise within an organization, while systemic risks are inherent to the industry but modifiable to some degree. In contrast, external risks, such as regulatory changes, economic shifts, and environmental uncertainties, fall beyond an organization's control. These risks can be classified into *most* and *least* important based on their impact on project outcomes. The most significant risks include safety hazards, quality issues, design flaws, and labor shortages, while less critical risks encompass government policy changes, permitting delays, ordinances, and inflation (Ogbu & Adindu, 2019; Muhammed & Muhammed, 2021).

In their study, Ogbu and Adindu (2019) identified four critical direct risk factors affecting project outcomes: site environment and location, market or financial and socio-economic factors, contractor resources, and design or management risks. Each category is further influenced by multiple associated risk variables. For example, unfavorable site conditions, market fluctuations, or resource misallocation can create cascading effects that compromise project timelines and quality standards.

Sheen et al. (2017) emphasize the importance of distinguishing risk sources from their effects, asserting that project risks manifest in three major ways: (1) failing to stay within the allocated cost budget, forecast, or tender; (ii) failing to meet time constraints for approvals, design, construction, or project occupancy; and (iii) failing to achieve required technical standards related to quality, functionality, fitness for purpose, safety, and environmental preservation.

The priorities of key stakeholders often align with achieving planned objectives concerning scope, quality, time, cost, and contributions to both the project organization and society at large (Kloppenberg, 2012). Stakeholders' philosophies and practices greatly influence the effectiveness of an organization's risk management. Ogbu and Adindu (2019) argue that successful risk mitigation depends on integrating risk management strategies into organizational processes and fostering a culture of accountability.

Failure to meet cost, time, or technical requirements can result in substantial financial losses and reputational damage (Sheen et al., 2017). Moreover, project stakeholders—including clients, professional advisors, contractors, and suppliers—bear the responsibility of identifying risk sources and developing appropriate risk management strategies tailored to their respective roles. This stakeholder-centric approach ensures proactive risk identification and mitigation at each project stage.

Adindu (2015) highlights the importance of equipping stakeholders with the skills required to manage project risks effectively. A critical tool for achieving this is the *risk register*, which systematically documents potential risks, their probabilities of occurrence, and associated mitigation measures. A well-maintained risk register serves as a central repository for tracking risk-related information and aids stakeholders in identifying, analyzing, and prioritizing risks throughout the project lifecycle (Ogbu & Adindu, 2019).

Baranoff et al. (2012) emphasize that risk assessment serves as a survival strategy for organizations operating in volatile, uncertain, complex, and ambiguous environments. By adopting a structured risk management approach, organizations can thrive in such environments and improve the likelihood of project success. An information-driven risk management process that prioritizes critical risk factors is fundamental to achieving project objectives while minimizing potential disruptions.

2.4. Mass Housing Projects in Nigeria

Housing represents a critical component of social infrastructure in Nigeria, serving as a cornerstone for socio-economic development across various sectors. Moore (2019) reports that Nigeria's current housing stock is alarmingly low, with only 23 housing units per 1,000 inhabitants. According to the Centre for Affordable Housing Finance in Africa (UN Cartographic Section, 2014), Nigeria's housing deficit was conservatively estimated at 17 million dwelling units. More recent statistics indicate that this figure surged to approximately 20 million units by January 2019, marking a 15% increase from the previous year (Moore, 2019). Bridging this housing gap would require Nigeria to deliver approximately 1 million housing units annually (Adindu et al., 2020).

The housing deficit is not unique to Nigeria but remains a challenge across many African countries striving to provide adequate infrastructure. Table 1 presents a comparative analysis of the housing deficits in six selected African countries, as presented by Moore (2019) from the Centre for Affordable Housing Finance in Africa (CAHF).

Table 1 Housing Deficit of Six Selected African Countries

S/No	Country	Year	Estimated Population (2016-2019)	Estimated Housing Deficit (2019)
1	Nigeria	2016-2019	185-200 million	18-22 million units
2	Ghana	2016-2019	28-30 million	1.7-2.6 million units
3	Kenya	2016-2019	45-52 million	2 million units
4	Uganda	2016-2019	37-43 million	1.7-2 million units
5	South Africa	2016-2019	56-58 million	2.5 million units
6	Ethiopia	2016-2019	98-103 million	1.2 million units

Source: Affordable Housing Investment Summit, (2019)

Nigeria's housing crisis is particularly stark when compared to global housing affordability rates. Moore (2019) notes that only 10% of eligible homeowners in Nigeria can afford housing, a significant disparity when compared to countries such as the USA (72%), UK (78%), China (60%), and Korea (92%). This affordability gap continues to widen due to rapid urbanization, population growth, and the lack of corresponding infrastructural development. As a result, many urban areas experience high rents, severe overcrowding, and deteriorating living conditions (Muhammad et al., 2015).

The housing crisis is especially pronounced in Northern Nigeria, where housing shortages are more severe relative to the region's large population. To address this challenge, the Mass Housing Scheme was introduced as a collaborative effort involving the public and private sectors. Under this initiative, the Real Estate Developers Association of Nigeria (REDAN) has played a pivotal role in enabling the organized private sector to provide affordable housing solutions, particularly for low- and middle-income groups.

However, effective implementation of mass housing projects depends on the involvement of beneficiaries throughout the project lifecycle. Bashari et al. (2019), in a study of Jigawa residents in North West Nigeria, emphasized that beneficiaries prefer active participation from the project's inception to ensure their specific user requirements are met. Similarly, Zarewa (2019) underlines the importance of executive support and public participation as crucial factors for ensuring that mass housing projects deliver tangible value to end-users.

Despite these efforts, many mass housing projects across Nigeria continue to face significant challenges. Moore (2019) highlights persistent issues such as delays, project abandonment, and frequent disputes arising from risks related to time and cost overruns. These challenges emphasize the urgent need for improved risk management strategies to ensure the successful delivery of mass housing infrastructure.

3. METHODS

3.1. Research Design

This study adopted a mixed-method research design, combining both qualitative and quantitative approaches. Data were collected through structured questionnaires administered to a population of 720 construction industry professionals actively involved in mass housing infrastructure projects across the 20 northern states of Nigeria. The analysis utilized both descriptive and inferential statistical methods. Descriptive statistics, such as frequencies, percentages, and

rankings, were employed to summarize the data. Inferential statistics, including regression analysis and Pearson Moment Correlation, were used to explore relationships and test hypotheses derived from the respondents' feedback.

3.2. Research Population

A research population is defined as the large group of individuals or objects that form the primary focus of a scientific inquiry (Mohammed, 2017). According to Kolo (2013), a population consists of individuals with shared characteristics relevant to a study. This study's population comprised 720 construction professionals, including Project Managers, Architects, Quantity Surveyors, Builders, Civil Engineers, and other allied professionals within the construction sector.

The participants were purposively selected to ensure the representation of professionals most relevant to the research objectives. These individuals were drawn from various organizational entities, including Donor/Multilateral Agencies, Public-Private Partnerships (PPP), Federal Housing, State Housing, Local Government Housing, and Private Investor Initiatives (PII).

The study covered professionals across the 20 northern states, which are divided into three geopolitical zones:

1. North West states that include Zamfara (ZF), Sokoto (SO), Kaduna (KD), Kebbi (KB), Katsina (KT), Kano (KN), and Jigawa (JG).
2. North Central states that consist of Niger (NI), Kogi (KG), Nassarawa (NA), Plateau (PL), Benue (BN), Kwara (KW), and the Federal Capital Territory (FCT) Abuja.
3. North Eastern states that comprise Bauchi (BA), Borno (BO), Taraba (TA), Adamawa (TA), Gombe (GO), and Yobe (YO).

The purposive sampling technique was deemed appropriate for this study, as it enables the selection of participants with knowledge relevant to answering the research questions effectively.

Figure 1 Map of Nigeria (Political)
(Source: UN Cartographic Section)

3.3. Sampling Frame and Size

A sampling frame refers to the material source or list from which a sample is drawn (Dubey & Kothari, 2022). In this study, the sampling frame included construction professionals who were conveniently selected from six ownership categories engaged in mass housing infrastructure projects. These categories are Donor/Multilateral Agencies, Public-Private Partnerships (PPP), Federal Housing, State Housing, Local Government Housing, and Private Investor Initiatives.

3.4. Methods of Data Collection and Analysis

Data collection is a fundamental part of any empirical study, broadly categorized into primary and secondary data (Douglas, 2015). This study relied on primary data, which were collected using a structured questionnaire. The questionnaire adopted a 5-point Likert scale based on the framework provided by Enhassi et al. (2009). The scale options included: Strongly Agree (SA), Agree (A), Moderately Agree (MA), Disagree (D), and Strongly Disagree (SD). The variable factors investigated were derived from responses provided by project stakeholders and aligned with earlier studies by Kloppenberg (2012).

The study was conducted over a 38-month period, beginning in April 2019. However, several setbacks occurred during the data retrieval stage in late 2020 due to disruptions caused by the COVID-19 pandemic. To analyze the data, the study employed the Relative Vulnerability Index (RVI) methodology, adapted from Fergany et al. (2019) and Sheen et al. (2017). The RVI is calculated as follows:

$$RVI = \frac{\sum_{i}^{5} a_i x_i}{5\sum_{i=0}^{5} x_i} \; (0 \leq RVI \leq 1)(1) \qquad (1)$$

$$RVI = \frac{\sum(a_i x_i + a_2 x_2 + a_3 x_3 + \cdots + a_n x_n)}{\sum(x_1 + x_2 + x_3 + \cdots + x_n} \qquad (2)$$

The study calculated the Weighted Average (WA) for the three geopolitical zones in Northern Nigeria as follows:

- North-West Geo-zone (nwgz)
- North-Central Geo-zone (ncgz)
- North-East Geo-zone (negz)

The Weighted Average (WA) is calculated for each geo-zone and expressed as follows:

- WA (nwgz) = Weighted Average for the North-West Geo-zone
- WA (ncgz) = Weighted Average for the North-Central Geo-zone
- WA (negz) = Weighted Average for the North-East Geo-zone

The Cumulative Weighted Average (CWA) is then calculated by summing the weighted averages of all the geopolitical zones, as shown in Equation (3):

$$CWA = \sum \left[WA_{(nwgz)} + WA_{(ncgz)} + WA_{(negz)} \right] \qquad (3)$$

To determine the Maximum Weighted Average (MWA), it was assumed that all respondents selected "Strongly Agree (SA)" for all items on the 5-point scale, with a maximum score of 5 points. The MWA for each geo-zone was calculated as follows:

- MWA (nwgz) = Maximum Weighted Average for the North-West Geo-zone

- MWA (ncgz) = Maximum Weighted Average for the North-Central Geo-zone
- MWA (negz) = Maximum Weighted Average for the North-East Geo-zone

The cumulative Maximum Weighted Average (CMWA) is then computed by summing the maximum weighted averages of all the geo-zones, as expressed in Equation (4):

$$CWA = \sum \left[MWA_{(nwgz)} + MWA_{(ncgz)} + MWA_{(negz)} \right] \quad (4)$$

Finally, the Relative Vulnerability Index (RVI) is determined by dividing the CWA by the CMWA, as shown in Equation (5):

$$RVI = \frac{CWA}{CMWA} \quad (5)$$

4. RESULTS AND DISCUSSION

4.1. Results

This section presents the key findings of the study, including respondent demographics and results from the RVA. The RVI was used to analyze risks across roles and responsibilities (RNP), scope and requirements (RSR), and operations (ROO) performance factors.

In total, 720 questionnaires were distributed across 20 Northern Nigerian states, with 465 valid responses returned, representing a 64.58% response rate. Berekhoven (47) states that written surveys typically achieve response rates of 15–60%, which indicates a high level of respondent interest in this study. The internal consistency of the data was validated using Cronbach's Alpha and Composite Reliability (CR), as recommended by Hair et al. (2019). Cronbach's Alpha and CR values range between 0 and 1, with values above 0.6 considered acceptable (Isaacs, 2019). In this study, the CR value of 0.75 confirmed the reliability and robustness of the dataset for further analysis.

Table 2 presents an analysis of respondents based on their highest educational qualifications. Of the 465 respondents, 11.18% possess an OND/ND, 55.70% hold an HND/BSc, 15.91% have an MSc/Equivalent, 5.59% hold a PhD, and 11.62% possess Trade/Other certificates. These results indicate that over 77.20% of respondents have qualifications ranging from HND to PhD, demonstrating that the majority had sufficient intellectual capacity to comprehend the study and respond effectively to the issues requiring their judgment. This highlights the high reliability of the responses, as they are based on informed knowledge.

The table also provides a descriptive analysis of respondents by profession: 11.40% are project managers, 21.08% are architects, 17.32% are quantity surveyors, 19.96% are builders, 21.71% are civil engineers, and 8.83% are from other allied construction professions. This distribution indicates fair representation from various professional groups within the construction industry. These professional groups are actively involved in day-to-day activities involving risks, qualifying them as relevant stakeholders for the study's population frame.

Furthemore, Table 2 also presents the respondents' construction industry experience. Of the respondents, 14.41% have 1-4 years of experience, 18.28% have 5-9 years, 22.58% have 10-14 years, 22.80% have 15-19 years, and 21.93% have a minimum of 20 years' experience. Therefore, over 67.31% of respondents have more than 10 years of experience in the construction industry, further supporting the reliability of the data collected from the field survey.

Table 2 Descriptive Statistics of Respondents

Zone / Factors	NWGZ							NCGZ							NEGZ						%
	STATES							STATES							STATES						
EDUCATION	ZF	SO	KD	KB	KT	KN	JG	NI	KO	NA	PL	BN	KW	FCT	BA	BO	TA	AD	GO	YO	
OND/ND	2	-	4	3	2	3	2	4	4	3	2	2	3	1	4	5	3	3	-	2	11.18
HND/BSc	12	10	14	13	10	11	16	15	12	13	14	11	16	15	13	14	12	11	15	12	55.70
MSc/Equiv	3	5	4	3	4	5	2	3	3	4	6	3	5	5	3	3	4	2	4	3	15.91
PhD	-	-	1	-	-	2	-	3	2	1	2	2	3	5	2	1	-	-	2	-	5.59
Trade Certs/Others	5	3	-	2	3	2	1	2	3	5	4	2	1	4	2	3	2	3	4	3	11.62
DISCIPLINE																					
Project Manager	1	-	3	2	2	3	2	4	3	5	4	2	3	4	5	3	4	1	2	-	11.40
Architect	5	3	6	4	4	7	5	6	4	5	4	4	6	6	5	3	6	4	5	6	21.08
Quantity Surveyor	4	4	5	3	3	5	3	5	4	3	5	3	4	4	4	6	2	3	4	4	17.32
Builder	6	5	4	5	4	2	3	5	7	4	7	5	4	6	4	5	3	5	4	3	19.96
Civil Engineering	5	3	4	4	5	4	5	6	6	4	5	4	6	8	4	6	5	4	6	5	21.71
Other allied construction professions	2	3	2	2	1	2	3	1	-	5	3	2	5	2	2	3	1	2	4	2	8.53
EXPERIENCE																					
1-4	3	3	4	2	2	4	3	5	4	3	4	2	5	4	3	2	4	3	5	2	14.41
5-9	5	4	3	5	4	3	3	6	5	4	4	3	5	6	4	5	4	3	4	5	18.28
10-14	4	5	5	4	3	4	5	4	4	7	5	5	10	8	7	6	4	6	5	4	22.58
15-19	5	3	4	6	4	5	7	8	5	6	7	6	4	5	5	8	3	4	5	6	22.80
20-Above	5	3	8	3	5	7	3	4	6	6	8	4	4	7	5	5	6	3	6	3	21.93
Total 465	22	18	24	20	19	23	21	27	24	26	28	20	28	30	24	26	21	19	25	20	100

Source: Authors Field Survey (2019 & 2020)
North-West Geopolitical Zone (NWGZ), North-Central Geopolitical Zone (NCGZ), North-East Geopolitical Zone (NEGZ)

The RVI is a helpful tool for understanding the RFP of various project roles based on data from different geopolitical zones. The RVI value provides insight into the vulnerability of certain risk factors by analyzing the level of agreement among respondents using the WA and the maximum weighted average (MWA) for each geopolitical zone.

Step-by-Step Illustration of RVI Calculation for Serial No. 1 (Project Lacks End-User Value)

1. Weighted Average (WA) Calculation:
   The WA is calculated for each of the three geopolitical zones: North-West (nwgz), North-Central (ncgz), and North-East (negz). The formula involves multiplying the number of respondents selecting each Likert scale option by the respective score (1 to 5).
   a. North-West Geo-Zone (NWGZ)
      Strongly Agree (SA) $= 5 \times 43 = 215$
      Agree (A) $= 4 \times 36 = 144$
      Moderately Agree (MA) $= 3 \times 33 = 99$
      Disagree (D) $= 2 \times 16 = 32$
      Strongly Disagree (SD) $= 1 \times 18 = 18$
      $WA_{(NWGZ)} = 508$
   b. North-Central Geo-Zone (NCGZ)
      Strongly Agree (SA) $= 5 \times 51 = 255$
      Agree (A) $= 4 \times 47 = 188$

Moderately Agree (MA) = 3 × 42 = 126
Disagree (D) = 2 × 26 = 52
Strongly Disagree (SD) = 1 × 18 = 18
$WA_{(NCGZ)}$ = 639

c. North-East Geo-Zone (NEGZ)
Strongly Agree (SA) = 5 × 37 = 815
Agree (A) = 4 × 33 = 132
Moderately Agree (MA) = 3 × 33 = 99
Disagree (D) = 2 × 13 = 26
Strongly Disagree (SD) = 1 × 19 = 19
$WA_{(NEGZ)}$ = 461

2. Cumulative Weighted Average (CWA) Calculation:
The CWA is calculated by summing the WA values of all three zones.
CWA = Cumulative Weighted Average
$= \sum\left[WA_{(NWGZ)} + WA_{(NCGZ)} + WA_{(NEGZ)}\right]$
= 508 + 639 + 461
= 1608

3. Maximum Weighted Average (MWA) Calculation:
The MWA represents the hypothetical maximum score each zone could achieve if all respondent selected "Strongly Agree" (SA) for all question.
a. North-West Geo-Zone (NWGZ)
Strongly Agree (SA) for all = 5 × (43 + 36 + 33 + 16 + 18) = 730
b. North-Central Geo-Zone (NCGZ)
Strongly Agree (SA) for all = 5 × (51 + 47 + 42 + 26 + 18) = 920
c. North-East Geo-Zone (NEGZ)
Strongly Agree (SA) for all = 5 × (37 + 33 + 33 + 13 + 19) = 675

4. Cumulative Maximum Weighted Average (CMWA) Calculation:
The CMWA is calculated by summing the MWA values of all three zones.
CMWA $= \sum\left[MWA_{(NWGZ)} + MWA_{(NCGZ)} + MWA_{(NEGZ)}\right]$
= 730 + 920 + 675

5. RVI Calculation:
The Relative Vulnerability Index (RVI) is computed by dividing the CWA by the CMWA:
RVI = CWA ÷ CMWA
= 1608 ÷2325
= 0.6916

The RVI value for "Project Lacks End-User Value" (Serial No. 1) is 0.6916, indicating a relatively high risk of failure in performance (RFP).

Table 3 evaluated the 'Risk of Non-Performance of Project Roles', specifically assessing factors such as corporate governance, decision-making, and project monitoring. For example, the variable 'Project Lacks End-User Value' showed the highest CWA of 1608 across the North-West, North-Central, and North-East geopolitical zones, resulting in an RVI of 0.6916. This value indicates a high RFP, ranking 1st among the other factors.

Other critical factors identified under Risk of Non-Performance included:

- Corporate leadership is lacking (CWA: 1599, RVI: 0.6867, RFP: 2)
- Corporate environment unsuitable (CWA: 1598, RVI: 0.6873, RFP: 3)
- Project has weak governance (CWA: 1595, RVI: 0.6860, RFP: 4)
- Change in project ownership/senior management affects deliverables (CWA: 1593, RVI: 0.6852, RFP: 5)

These factors indicate significant concerns regarding the project's governance and alignment with end-user requirements, highlighting the need for better decision-making and corporate leadership to improve performance outcomes.

Table 3 Assessment of 'Risk of Non-Performance of Project Roles'

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Non-Performance of Project Roles'	SA 5	A 4	MA 3	D 2	SD 1	SA 5	A 4	MS 3	D 2	SD 1	SA 5	A 4	MA 3	D 2	SD 1	CWA	RVI	RFP
1	Project lacks end user value	43	36	33	16	18	51	47	42	26	18	37	33	33	13	19	1608	0.6916	1st
2	Corporate leadership is lacking	32	35	36	24	12	48	51	33	31	17	36	43	38	15	13	1599	0.6877	2nd
3	Corporate environment is unstable	31	43	34	24	13	45	52	40	26	22	33	38	31	26	9	1598	0.6873	3rd
4	Project has a weak governance	36	44	34	18	13	36	54	48	25	20	30	48	31	14	15	1595	0.6860	4th
5	Mismatch between corporate needs and project objectives	37	41	37	16	16	48	48	41	26	20	28	45	30	17	14	1593	0.6852	5th
6	Occurrence of unethical behaviour	38	38	33	20	13	47	53	39	26	16	30	48	24	16	17	1589	0.6834	6th
7	Corporate management loses interest on the project	40	40	33	18	14	41	52	40	32	24	30	31	38	19	17	1573	0.6766	7th
8	Corporate management does not monitor the project	36	45	34	14	18	37	52	38	31	23	34	35	37	17	11	1566	0.6736	8th
9	Corporate management does not make decision at critical junctures	34	40	37	16	15	49	38	42	32	22	27	48	31	17	12	1563	0.6723	9th
10	Change in project	35	42	33	19	16	40	46	45	33	19	25	46	30	17	17	1550	0.6667	10th

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Non-Performance of Project Roles'	SA 5	A 4	MA 3	D 2	SD 1	SA 5	A 4	MS 3	D 2	SD 1	SA 5	A 4	MA 3	D 2	SD 1	CWA	RVI	RFP
	ownership/Senior Management affects deliverables																		

Source: Authors Field Survey (2019 & 2020)

Table 4, which evaluated the 'Risk of Scope and Requirements Performance', revealed similar patterns of vulnerability. The factor 'Weak project monitoring and control' showed a CWA of 1588, the highest in this category, with an RVI of 0.6830, ranking 1st. This emphasizes the importance of robust monitoring and control mechanisms in mitigating risks.

Other notable factors under Scope and Requirements included:

- Deliverables are unclear (CWA: 1577, RVI: 0.6783, RFP: 2)
- Goals are unclear (CWA: 1572, RVI: 0.6761, RFP: 3)

The results point to the critical need for better clarity and communication regarding project goals and deliverables to reduce risks and enhance project success.

In conclusion, the RVI analysis across both tables show significant risks in both project roles and scope performance. Key areas such as end-user value, corporate leadership, and project monitoring/control emerged as high-risk factors, necessitating focused attention from stakeholders to improve overall project outcomes in mass housing infrastructure in Northern Nigeria.

Table 4 Assessment of 'Risk of Scope and Requirements (RSR) Performance'

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Non-Performance of Project Roles'	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	CWA	RVI	RFP
1	Weak project monitoring and control	38	38	29	21	22	42	54	39	26	22	34	44	28	18	12	1588	0.6830	1st
2	Deliverables are unclear	38	39	35	18	17	45	51	38	25	24	30	45	24	19	16	1577	0.6783	2nd
3	Goals are unclear	32	44	31	22	22	39	51	37	30	27	32	47	30	16	10	1572	0.6761	3rd
4	Project not broken into manageable sizes	31	35	35	22	15	44	55	39	24	20	32	38	28	16	17	1529	0.6576	4th
5	Frozen requirements are lacking	36	37	33	21	18	36	47	42	31	25	30	37	37	17	14	1525	0.6559	5th
6	Misunderstanding of project End-User Requirements	38	39	30	23	15	34	53	43	26	27	33	38	31	16	17	1516	0.6520	6th

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Non-Performance of Project Roles'	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	CWA	RVI	RFP
7	Project changes are poorly managed	34	27	28	26	20	37	57	41	28	20	36	38	30	15	17	1515	0.6516	7th
8	Weak project planning	35	42	31	22	15	50	46	43	24	20	34	41	28	20	12	1509	0.6490	8th
9	Non agreement on project objectives	30	41	37	21	18	33	50	44	28	28	26	35	32	22	16	1492	0.6417	9th

Source: Authors Field Survey (2019 & 2020)

Table 5 assessed the 'Risk of Operations' performance and identified key operational factors that impact the success of projects. The analysis revealed that under-budgeting leading to project underfunding was the most critical factor, with a Cumulative Weighted Agreement (CWA) of 1572, a Relative Vulnerability Index (RVI) of 0.6761, and a Risk of Failure in Performance (RFP) ranking of 1st. This finding aligns with Sheen et al. (2017), who emphasized that project-related risks, such as underfunding, often result in failure to adhere to cost budgets, which can cause delays or even lead to project abandonment. The implication of underfunding is severe, as it can result in significant delays, cost overruns, or complete abandonment of the project. To mitigate this, careful attention is needed to ensure proper budget planning and adequate funding allocations from the outset.

Other significant risk factors in the 'Risk of Operations' category include development budgets prematurely set before scope definition (CWA: 1547, RVI: 0.6654, RFP: 2), and lack of adequate involvement of stakeholders (CWA: 1527, RVI: 0.6568, RFP: 3). Additionally, project personnel failing to manage end-user expectations (CWA: 1524, RVI: 0.6555, RFP: 4), and project planners failing to identify all stakeholders (CWA: 1521, RVI: 0.6542, RFP: 5) were also highlighted as significant risks. Further risks identified include wrong cost estimates due to ineffective costing techniques (CWA: 1515, RVI: 0.6516, RFP: 6), projects prompted by a higher priority project (CWA: 1497, RVI: 0.6439, RFP: 7), lack of cooperation from project end-users (CWA: 1495, RVI: 0.6430, RFP: 8), and artificial deadlines set for project activities (CWA: 1494, RVI: 0.6426, RFP: 9).

These findings highlight the operational complexities that can hinder the successful execution of mass housing infrastructure projects. Factors such as inadequate budget planning, poor stakeholder involvement, and ineffective cost estimation techniques significantly contribute to the risk of operational failure. Addressing these issues is critical for improving the performance and completion of mass housing projects.

Table 5 Assessment of 'Risk of Scope and Requirements (ROO) Performance'

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Operation Performance'	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	CWA	RVI	RFP
1	Under-budgeting leading to project underfunding	40	48	32	18	14	38	47	43	33	22	28	35	24	19	19	1572	0.6761	1st

S/N	Variable Factors	NWGZ					NCGZ					NEHZ					Assessment		
	"Risk of Operation Performance'	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	SA 5	A 4	M 3	D 2	SD 1	CWA	RVI	RFP
2	Development budget prematurely set before scope definition	34	53	35	16	9	34	50	40	30	27	29	35	31	24	16	1547	0.6654	2nd
3	Lack of adequate involvement of end-users	37	40	41	17	15	34	43	47	30	29	29	37	29	21	16	1527	0.6568	3rd
4	Project personnel failed to manage end-user expectation	35	48	44	19	11	37	44	40	32	30	28	36	35	16	20	1524	0.6555	4th
5	Project planners failed to identify all stakeholders	32	47	35	19	14	30	51	44	27	31	29	35	32	25	14	1521	0.6542	5th
6	Wrong cost estimates owing to ineffective costing techniques	27	39	42	20	18	39	52	38	30	24	26	36	35	22	16	1515	0.6516	6th
7	Project prompted by a higher priority project	25	42	40	24	16	34	49	41	34	26	25	38	33	22	17	1497	0.6439	7th
8	Cooperation from project end-users is lacking	34	49	34	13	17	31	48	39	35	30	23	33	33	25	24	1495	0.6430	8th
9	Artificial deadlines set for project activities	34	50	32	16	15	26	48	48	33	25	25	36	30	21	23	1494	0.6426	9th

Source: Authors Field Survey (2019 & 2020)

Table 6 highlights the correlation between the variables examined in this study, indicating a strong relationship among the variables, particularly RNP (Risk of Non-Performance) with RSR (Risk of Scope and Requirements) and ROO (Risk of Operations). The correlation coefficients are .858 and .910 respectively, demonstrating high correlation between these variables. Similarly, there is a correlation of .858 between RSR and the other variables (RNP and ROO), and a correlation of .910 between ROO and the other two factors (RNP and RSR), confirming strong interrelationships across these variables. The Sig. values (<0.05) further indicate that these correlations are statistically significant, affirming the model's reliability.

Table 6 Correlations

		RNP	RSR	ROO
RNP	Pearson Correlation	1	.858**	.910**
	Sig. (2-tailed)		.003	.001
	N	10	9	9
RSR	Pearson Correlation	.858**	1	.910**
	Sig. (2-tailed)	.003		.001

		RNP	RSR	ROO
	N	9	9	9
	Pearson Correlation	.910**	.910**	1
ROO	Sig. (2-tailed)	.001	.001	
	N	9	9	9

** Correlation is significant at the 0.01 level (2-tailed)

Source: Authors Field Survey (2019 & 2020)

Table 7 presents an R-Square value of .891, showing that the combination of RNP and RSR effectively explains 89.1% of the variations in ROO, while the remaining variation is likely attributable to other factors not included in this study. According to Zaid (2015) and Verbeek (2019), an R-Square value closer to 1 indicates a strong goodness-of-fit for the model, suggesting that the model is a reliable tool for drawing inferences and conclusions. In this case, the R-Square value of .891 reflects a high goodness-of-fit, confirming the model's robustness (see Table 8).

Table 7 Model Summary

Model	R	R square	Adjusted R Square	Std. Error of the Estimate	R Square Change	Change Statistics			Sig. F Change
						F Change	df1	df2	
1	.944[a]	.891	.855	.00422	.891	24.638	2	6	.001

a. *Predictors: (Constant), RSR, RNP*

Source: Authors Field Survey (2019 & 2020)

Table 8 ANOVA[a]

Model	Sum of Squares	df	Mean Square	F	Sig.
	Regression	.001	.000	24.638	.001[b]
1	Residual	.000	.000		
	TOTAL	.001			

a. *Dependent Variable: ROO*

b. *Predictors: (Constant), RSR, RNP*

Source: Authors Field Survey (2019 & 2020)

The regression model shown in Table 9 illustrates the relationship between ROO, RNP, and RSR, and can be expressed as ROO = -.136 + .802(RNP) + .368(RSR). This equation suggests that for every one-unit increase in ROO, there is an expected 0.8% change in RNP and a 0.37% change in RSR. This regression analysis show the substantial impact that RNP and RSR have on ROO, reinforcing the importance of managing these risk factors to optimize project performance in mass housing projects.

Table 9 Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std.Error	Beta		
	(Constant)	-.136	.192		-.709	.505
1	RNP	.802	.427	.492	1.876	.110
	RSR	.368	.198	.487	1.859	.112

a. *Dependent Variable: ROO*

Source: Authors Field Survey (2019 & 2020)

4.2. Discussion of Findings

The study highlights key findings regarding mass housing estate developments in Northern Nigeria, with a primary issue being the lack of end-users' value, which ranked first in the Risk of Failure in Performance (RFP) assessment among the 10 identified 'roles and responsibilities' performance factors (see Table 3). This finding shows the failure of projects to meet the needs and requirements of beneficiaries, consistent with Bashari et al. (2019), who reported similar challenges in Jigawa, North West Nigeria. The implication is clear: there is an urgent need to engage project end-users during all phases of the project, including conceptual planning, design, documentation, contract award, execution, monitoring, control, commissioning, and post-contract audits. While studies by Alhammadi et al. (2020) and Al Hinai et al. (2020) address aspects of project development, they do not fully account for end-user integration, emphasizing a persistent gap in achieving project value.

Public participation is therefore crucial to ensure that mass housing projects deliver the intended value to beneficiaries, as highlighted by Zarewa (2019). This study reinforces the importance of aligning end-users' needs and aspirations throughout all phases of project development. Such alignment ensures that the final product corresponds with end-user expectations. The assessment of 'scope and requirements information' reveals that 'weak project monitoring and control' recorded the highest Relative Vulnerability Index (RVI) among the nine factors assessed (see Table 4). This indicates that planned project activities often drift, leading to wasted resources and incomplete deliverables. These findings are corroborated by Mtana et al. (2023), who identified similar inefficiencies. This outcome aligns with the procedural/project risk vulnerability concept presented by Borghesi & Gauglenzi (2013) but contrasts with the findings of Ingle & Mahesh (2020), who concentrated on other performance dimensions in construction projects.

The results suggest that project teams must prioritize the development and implementation of robust monitoring and control systems across the project development cycle. Effective monitoring mechanisms are essential to mitigate the greatest risks to performance, particularly concerning the achievement of project scope and requirements (Kloppenberg & Petrick, 2020).

Moreover, the study identifies the 'risk of operations performance' factor, particularly 'under-budgeting leading to project underfunding,' as the top-ranked factor in the RFP assessment (see Table 5). This finding aligns with Muhammed et al. (2022a), who describe underfunding as a key indicator of project failure. The inability to meet budgeted costs or forecasts highlights the importance of addressing stakeholder priorities, including scope, quality, time, and cost. A critical issue is that operational underfunding in mass housing projects often originates from insufficient pre-contract budgeting.

The analysis further reveals a strong correlation between risks associated with roles and responsibilities, scope, requirements, and operational performance, as evidenced by a correlation coefficient of 0.91 (see Table 6). This finding demonstrates the interconnectedness of these factors in driving project outcomes. Specific risks, such as estimation inaccuracies, material delivery delays, payment issues, and poor coordination, as described by Muhammed et al. (2022b), contribute significantly to project failures and the inability to meet end-user requirements. Additionally, Table 9 confirms that the influence of roles, responsibilities, scope, and requirements on operational performance significantly affects project delivery. These risks are shown to result in delays, failures, or even project abandonment, as also noted by Muhammed et al. (2022a).

5. CONCLUSION

This study addresses the critical need to evaluate the risks associated with mass housing infrastructure provisioning in Northern Nigeria, considering the substantial investments made by state and non-state actors to alleviate the significant housing shortages in the region. The findings highlight that many mass housing projects have failed to meet post-occupancy needs, highlighting the importance of assessing project team performance risks. The key areas examined include roles and responsibilities, scope and requirements, and operational aspects of mass housing projects, which are fundamental to their successful delivery.

The study concludes that a lack of end-user value remains the most critical factor contributing to project underperformance, ranking highest in the Risk of Non-Performance of Project Roles. This finding indicates that mass housing projects often fail to address the needs and expectations of beneficiaries, further emphasizing the necessity of involving end-users from the earliest stages of project development. From conceptual planning and design to execution, monitoring, and post-occupancy evaluations, engaging beneficiaries is vital to ensuring that mass housing projects serve their intended purpose effectively. Furthermore, weak project monitoring and control emerged as the most significant issue under the Risk of Scope and Requirements Performance. This highlights the inefficiencies in tracking planned activities, which often result in resource wastage and delays in project completion. These findings reinforce the need for robust systems to monitor and control project deliverables across all phases of development, ensuring better alignment with project goals.

Additionally, under-budgeting, which leads to project underfunding, was identified as the most significant risk under the Risk of Operations Performance. This result aligns with previous studies emphasizing that insufficient funding during the operational phase often hinders the successful execution of mass housing projects. A reliable and institutionalized project costing and budgeting system is therefore essential to address cash flow challenges, ensuring that projects receive adequate funding from inception to completion. This will help mitigate financial constraints that commonly lead to delays, cost overruns, or project abandonment. Addressing these risks requires effective planning, strong institutional frameworks, and a clear focus on delivering value to end-users.

Despite the significance of these findings, the study acknowledges certain limitations. Political dynamics, particularly the appointment of project team members who may lack expertise in risk management, pose challenges to the successful implementation of the proposed policy recommendations. Ensuring that project teams are composed of competent professionals with the requisite skills in risk management is crucial for overcoming these limitations and achieving the desired project outcomes. Institutionalizing these recommendations requires strong political will and stakeholder collaboration to prioritize performance-driven strategies in mass housing infrastructure projects.

For a broader perspective, further research is strongly recommended in other geopolitical zones of Nigeria, including the South-East, South-West, and South-South regions. Conducting similar studies across these regions will provide a more comprehensive understanding of mass housing infrastructure nationwide. It will also account for the substantial capital investments made by governments, organizations, and individuals in these regions. Such studies will help identify regional-specific risks and challenges in mass housing projects, enabling policymakers to develop tailored solutions that address the unique needs of each region. This expanded understanding will contribute to the development of more effective strategies to improve housing delivery across Nigeria, ensuring sustainable and impactful investments in mass housing infrastructure.

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STRATEGIC KNOWLEDGE MANAGEMENT FRAMEWORK FOR TECHNOLOGY TRANSFER IN INDONESIAN JOINT OPERATION CONSTRUCTION PROJECTS

Yudha Trimuliadi Suryana[1] and Ayomi Dita Rarasati[1*]

[1]*Departement of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia*

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ABSTRACT

Joint Operation (JO) construction companies in Indonesia face persistent challenges in technology transfer, including misalignment between advanced technologies and organizational capacities. Knowledge management has been proposed as a strategic solution, but its implementation remains underdeveloped. This study develops a framework to enhance technology transfer in JO construction projects through improved knowledge management practices. Utilizing a mixed-methods approach, the research combines a literature review with an analytical hierarchy process, fuzzy set theory, and a simple additive weighting method, supported by data from selected respondents involved in the Jakarta Mass Rapid Transit (MRT) project (CP201). Key findings identify knowledge acquisition, utilization, and sharing as critical processes, with sub-criteria such as clarity of roles and responsibilities and external collaboration emerging as pivotal. The SECI (Socialization, Externalization, Combination, and Internalization) model is applied to guide the development of actionable strategies for effective knowledge management. This study contributes a tailored framework for Indonesian JO construction companies, bridging gaps in technology transfer and advancing organizational capabilities. Practical recommendations are provided to improve knowledge integration and foster sustainable growth in infrastructure projects.

Keywords: Analytical hierarchy process; Knowledge management; SECI; Technology transfer

1. INTRODUCTION

Indonesia's rapid economic growth has significantly increased the demand for extensive and complex infrastructure development. Major projects, such as highway networks, ports, and airports, are vital for supporting economic growth, enhancing connectivity, and improving societal welfare. According to the World Bank, Indonesia's infrastructure investment needs are estimated to reach approximately USD 500 billion by 2025 to sustain its economic growth trajectory (World Bank, 2021). To meet these demands, collaboration with foreign entities often becomes essential, particularly through Joint Operations (JO). Since its implementation in 1991, the JO concept in Indonesia's construction industry has been regulated through various policies, with the most recent revision under Ministerial Regulation-Public Works No. 10/PRT M/2014. These regulations emphasize the requirement for foreign construction companies to transfer technology to local partners, aiming to build local capabilities in project execution and management.

*Corresponding author's email: ayomi@ui.ac.id
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Despite this regulatory framework, JO construction companies in Indonesia face challenges in adopting advanced technology due to misalignments between available technology and organizational capacity. A 2019 study by the Indonesian Construction Services Development Board (LPJK) revealed that 65% of local construction companies struggle with the absorption and implementation of advanced technologies introduced by foreign partners (Indonesian LPJK, 2019). This issue is further complicated by requirements to prioritize domestic products when they meet the required specifications, adding layers of complexity to technology adoption. Challenges include limited technical expertise, insufficient training programs, and inadequate infrastructure to support the introduction of new technologies (LPJK, 2020).

Knowledge management (KM) offers a promising approach to overcoming these challenges. Defined as the systematic process of identifying, organizing, and sharing knowledge, KM can enable JO construction companies to align their organizational capacities with the advanced technologies introduced by foreign partners (Dalkir, 2013). By focusing on key KM processes, such as knowledge acquisition, utilization, and sharing, companies can facilitate effective technology transfer and bridge the gap between organizational readiness and technological advancements (Nonaka & Takeuchi, 1995).

The central research problem addressed in this study is the ineffective transfer of advanced technology within JO construction projects in Indonesia. This problem arises from several factors: misalignment between advanced technologies and organizational capabilities, regulatory requirements that prioritize domestic products, insufficient training programs for skill development, and the absence of a structured KM system to support technology transfer (OECD, 2018; Gboney, 2009).

This study aims to identify successful KM processes and strategies that can enhance the efficiency of technology transfer within JO construction projects, particularly in the MRT CP201 project. The specific objectives are: (1) to analyze the current state of technology transfer and KM practices in JO construction companies in Indonesia, (2) to identify key KM processes that facilitate effective technology transfer, (3) to develop strategic steps for implementing KM practices to improve technology transfer efficiency, and (4) to provide practical recommendations for JO construction companies to bridge the gap between advanced technology and organizational capability, thereby enhancing operational efficiency and product quality (Hartley, 2004; Davenport & Prusak, 1998).

By addressing these challenges and achieving these objectives, the research seeks to improve the operational efficiency and product quality of JO construction projects in Indonesia, ultimately contributing to the nation's economic growth and infrastructure development (Asian Development Bank, 2018; Global et al., 2019).

2. LITERATURE STUDY

In the context of construction in Indonesia, JO refers to a temporary collaboration between foreign and local construction service companies to undertake specific projects. Internationally, this concept is known as an International Construction Joint Venture (ICJV). The definition of JO has evolved over time within Indonesian government regulations. Initially, JO was defined as cooperation between foreign and local companies without forming a new legal entity (Minister of Public Works Regulation No. 50/PRT/1991). Subsequent revisions, such as Minister of Public Works Regulation No. 05/PRT/M/2011, refined this definition to emphasize technology transfer and capacity building for local partners (Indonesian LPJK, 2019; OECD, 2018). The latest revision, Ministerial Regulation-Public Works No. 10/PRT M/2014, further highlights the mandatory transfer of technology to strengthen local construction capabilities.

To address the challenges of technology transfer in JO projects, KM has emerged as a crucial framework. KM is defined as the systematic process of identifying, collecting, organizing, and utilizing knowledge to improve organizational performance and achieve a competitive advantage (Dalkir, 2013). Menon (2003) highlights the cultural and social aspects of KM, emphasizing the need for an environment that fosters collaboration and knowledge exchange. Nonaka and Takeuchi (1995) provide a foundational model for KM, known as the knowledge spiral, which comprises four key processes: socialization, externalization, combination, and internalization. These processes collectively facilitate the conversion of tacit knowledge into explicit knowledge and vice versa, ensuring that critical knowledge is effectively transferred and applied. This framework is particularly relevant to JO construction projects, where foreign partners bring advanced technologies that need to be transferred to and internalized by local organizations.

KM processes play a pivotal role in addressing technology transfer challenges within JO construction projects. According to Hwang (2020) and Yap & Toh (2020), KM processes can be categorized into four main stages: knowledge creation, acquisition, sharing, and utilization. Knowledge creation involves the development and updating of organizational knowledge through continuous efforts by individuals and teams. Knowledge acquisition focuses on capturing and organizing knowledge, often converting tacit knowledge into explicit formats for broader use. Knowledge sharing ensures the dissemination of critical information across the organization, fostering effective communication and collaboration among stakeholders. Finally, knowledge utilization involves applying the acquired knowledge to improve efficiency, reduce costs, and gain a competitive edge. In JO construction projects, these KM processes are essential for bridging the gap between advanced foreign technologies and local organizational capabilities, ensuring that transferred knowledge is both shared and effectively utilized.

Despite the importance of KM in technology transfer, JO construction projects face numerous challenges across different phases. These challenges can be broadly categorized into organizational, technical, communication, and implementation barriers. Organizational barriers include inadequate management support, limited stakeholder awareness, and a lack of technical expertise (Gboney, 2009). Technical challenges such as insufficient infrastructure, inconsistent standardization, and data security issues further hinder the effective adoption of new technologies (Czabke, 2008). Communication barriers, including unclear communication channels and cultural differences, exacerbate collaboration issues between foreign and local teams (Narula, 2005). Finally, implementation barriers arise from resistance to change, insufficient training programs, and mismatched technology design, which limit the practical application of transferred technologies (Czabke, 2008).

To overcome these challenges and support decision-making in JO construction projects, structured frameworks such as the Analytical Hierarchy Process (AHP), fuzzy sets, and the Simple Additive Weighting (SAW) method can be applied. Decision-making involves a series of steps, including problem identification, evaluation of alternatives, and the implementation of solutions (Oxford Dictionary, 2016). Anderson (2015) emphasizes the importance of the alternative selection stage, particularly in solving complex problems. AHP allows decision-makers to prioritize multiple criteria systematically, while fuzzy sets and SAW enable the evaluation of alternatives based on uncertain or qualitative data. Integrating these decision-making methodologies into KM processes can help JO construction companies identify the most critical barriers, prioritize solutions, and allocate resources effectively. By doing so, companies can enhance their ability to transfer and utilize advanced technologies, ultimately improving project outcome

The conceptual framework diagram (Figure 1) provides a structured approach for analyzing and implementing KM processes within JO construction projects, particularly focusing on technology transfer. The framework begins by identifying potential foreign investment opportunities and recognizing the influence of government policies that mandate technology transfer. The primary objective is to achieve successful technology transfer and implementation in JO construction projects by systematically addressing barriers to the process. To achieve this, the analysis employs methodologies to determine the importance of various influencing factors, the fuzzy sets method to assess implementation ratings, and a scoring method to derive alternative scores for KM processes. The study highlights three key KM processes: knowledge acquisition, knowledge usage, and knowledge sharing, which are critical for overcoming challenges in technology transfer. Specific implementation steps are outlined to improve technology transfer effectiveness, particularly within the Jakarta MRT CP201 project. This integrated framework serves as a strategic guide for JO construction companies in Indonesia, aiming to enhance technology transfer efficiency, bridge the existing technology gap, and ultimately improve project outcomes.

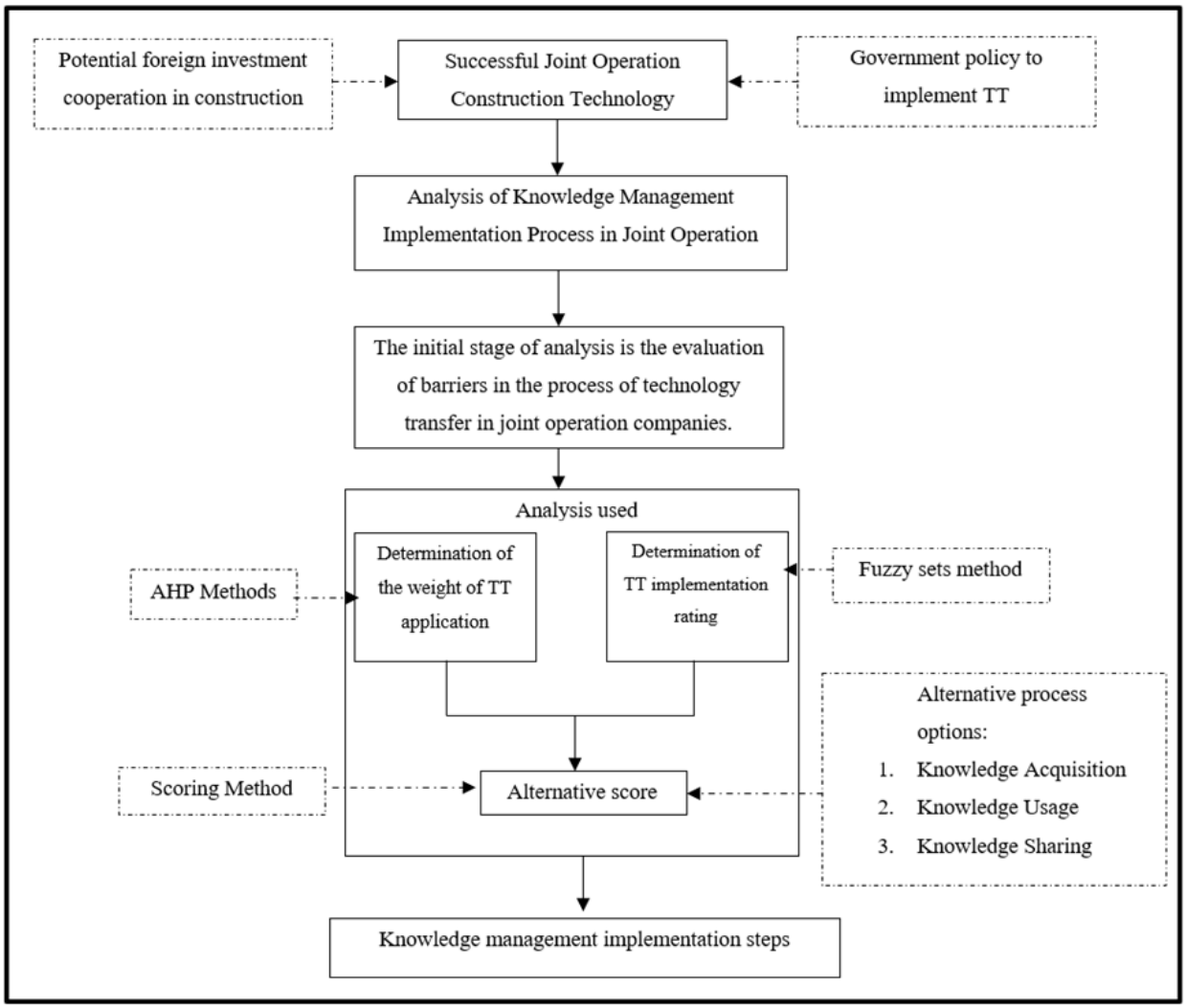

Figure 1 Conceptual Framework

3. METHODS

This study employs a mixed-methods approach, integrating both quantitative and qualitative methods to analyze the role of KM processes in improving technology transfer within JO construction projects. The research focuses specifically on the Jakarta MRT CP201 project, a

collaborative infrastructure initiative between Indonesia and Japan. Data were collected through structured surveys distributed to key stakeholders, including owners, contractors, consultants, and subcontractors involved in the project. To ensure the reliability and relevance of responses, participants were required to meet two criteria: a minimum of a bachelor's degree in a relevant field and at least five years of professional experience in the construction industry.

Two types of questionnaires were employed to gather comprehensive data. Questionnaire I collected information on the criteria statements and captured respondents' aspirations regarding the objectives of the KM processes, specifically focusing on knowledge acquisition, knowledge sharing, and knowledge utilization. Meanwhile, Questionnaire II employed pairwise comparisons, enabling respondents to evaluate the dominance of one criterion over another. These pairwise comparisons formed the basis for determining the relative importance of each criterion using the AHP.

The research focused on the Jakarta MRT project at Monas Station CP201, a collaborative project between Indonesia and Japan. Based on the analysis of various scholarly literature, a more effective KM model is proposed (Dalkir, 2013; Nonaka & Takeuchi, 1995; Davenport & Prusak, 1998), which includes three primary processes: Knowledge Acquisition, Knowledge Sharing, and Knowledge Utilization. Assessing these KM processes presents challenges due to the different approaches used to measure them effectively (Raudeliuniene, 2018). Therefore, the study proposes an integrated KM model comprising the three key processes: Knowledge Acquisition, Knowledge Sharing, and Knowledge Utilization.

The dependent variable in this study is the selection of the appropriate KM process type for the JO project, with a particular focus on the MRT CP201 project. The independent variables include factors influencing the technology transfer process within the JO project. These factors include management support, stakeholder awareness, human resource development, infrastructure and standardization, communication channels, training programs, and technology design compatibility. The criteria selection for the analysis is based on a comprehensive literature review of journals discussing knowledge acquisition, sharing, development, and utilization processes, considering various barriers encountered during these processes (see Table 1).

Table 1 Outlines the Independent Variables along with their Criteria and Sub-Criteria

No	Criteria		Sub Criteria	Reference
1	Knowledge Acquisition	Internal	Clarity of Roles and Responsibilities	(Kumar, Scheer, & Kotler, 2005), (Lall, 1992)
			Leadership Involvement and Support	(Antony & Coronado, 2002), (Husain, Dayan, & Benedetto, 2002)
			Skill and Comprehension Level	(Thorsteinsson & Tester, 2010)
			Team Stability	(Dutrenit, 2004), (Iammarino, Piva, Vivarelli, & Von Tunzelmann, 2008)
			Skill and Knowledge Matching	(Thorsteinsson & Tester, 2010)
			Communication Facilities	(Love & Gunasekaran, 1997)
		External	Cooperation and Partnership	(Bierly & Gallagher, 2007)
			Changes in Technology and Industry Standards	(Jagoda & Ramanathan, 2005)
			Limited Access to Resources	(Al-Thawwad, 2008)
			Stakeholder Policy	(Turk, 2009), (Szogs, 2010)
			External Regulations and Policies	(Sharma, Pablo, & Vredenburg, 2011)
			Uncertain Market Conditions	(Haleem, Khan, & Sushil, 2016)

No	Criteria		Sub Criteria	Reference
2	Knowledge Usage	Internal	Clarity of Roles and Responsibilities	(Iammarino, Piva, Vivarelli, & Von Tunzelmann, 2008)
			Adequate Training	(Thorsteinsson & Tester, 2010)
			Effectiveness of Organizational Policies	(Zahra & George, 2002)
			Incentives for Knowledge Sharing	(Thorsteinsson & Tester, 2010)
			Resistance to Change	(Stanleigh, 2008)
		External	Uncertain Market Conditions	(Haleem, Khan, & Sushil, 2016)
			Limited Access to Resources	(Al-Thawwad, 2008)
			Cooperation and Partnership	(Bierly & Gallagher, 2007)
			External Regulations and Policies	(Sharma, Pablo, & Vredenburg, 2011)
			Stakeholder Policy	(Turk, 2009), (Szogs, 2010)
			Changes in Technology and Industry Standards	(Jagoda & Ramanathan, 2005)
3	Knowledge Sharing	Internal	Clarity of Roles and Responsibilities	(Kumar, Scheer, & Kotler, 2005), (Lall, 1992)
			Knowledge Sharing Culture	(Thorsteinsson & Tester, 2010)
			Adequate Training	(Czabke, Hansen, & Grace, 2008)
			Knowledge-Task Match	(Thorsteinsson & Tester, 2010)
			Skill and Knowledge Matching	(Thorsteinsson & Tester, 2010)
			Incentives for Knowledge Sharing	(Thorsteinsson & Tester, 2010)
		External	Cooperation and Partnership	(Bierly & Gallagher, 2007)
			External Regulations and Policies	(Sharma, Pablo, & Vredenburg, 2011)
			Changes in Technology and Industry Standards	(Jagoda & Ramanathan, 2005)
			Limited Access to Resources	(Al-Thawwad, 2008)
			Security and Confidentiality Risks	(Meleka, 1985), (Gee, 1981)
			Geographic or Regional Barriers	(Madu, 1988)

Respondent selection in this research follows a non-random approach, meaning that the selection of elements from the sampling population does not rely on probability theory. This sampling design is suitable when the total number of elements in a population is unknown or difficult to identify individually. As a result, the selection of respondents is based on other factors (Kumar, 2011).

The expert judgment sampling method was employed to ensure the selection of respondents with the required expertise and relevance to the study's objectives. This method, as described by Kumar (2011), involves identifying individuals with proven knowledge in the field, formally inviting their participation, and collecting their input through structured approaches. Since there is no fixed sample size for decision-making surveys using the AHP, the number of respondents is determined by their level of expertise rather than statistical representation (Saaty, 2014).

In this study, expert respondents consisted of project managers and top management personnel directly involved in the MRT CP201 project. Respondents were selected based on two criteria: (1) involvement in the project for more than one year and (2) possession of at least a bachelor's degree in a relevant field.

The study collected two types of primary data to support the analysis. Weighting data were obtained through paired comparison surveys, where respondents evaluated the dominance of various criteria within the KM sub-criteria, providing input for calculating relative weights using AHP. Meanwhile, requirements data were gathered through questionnaires to identify the most suitable criteria for each KM process, offering deeper insights into factors influencing technology transfer.

The collected data were processed using a structured approach involving AHP, fuzzy sets, and the SAW method. The process included organizing the data, constructing hierarchical frameworks for AHP, defining fuzzy membership functions to manage uncertainties in responses, and assigning scores with SAW to systematically rank alternatives. These methods ensured an informed evaluation of KM processes and provided decision-making support for improving technology transfer in JO construction projects.

4. RESULTS AND DISCUSSION

This section presents the results and discussion based on the application of AHP, fuzzy sets, and SAW methodologies described earlier. The analysis evaluates both internal and external sub-criteria across the knowledge acquisition, usage, and sharing processes to identify the most critical factors influencing technology transfer in the MRT CP201 project.

Knowledge acquisition involves targeted technical training and consultations with relevant experts, ensuring that team members acquire the necessary expertise to perform effectively. Knowledge utilization focuses on integrating newly acquired knowledge into existing workflows, significantly improving operational efficiency and overall project performance. Meanwhile, knowledge sharing facilitates seamless collaboration and communication among team members and external stakeholders (Ismail & Daud, 2024). The development of a knowledge-sharing culture, coupled with the effective use of information technology, ensures the smooth flow of knowledge within construction projects, which is essential for successful technology transfer. Collectively, these processes serve as the foundation for achieving effective technology transfer in the MRT CP201 project, ultimately contributing to long-term project performance and sustainability.

In large-scale construction projects like the MRT CP201, where technical and operational knowledge is critical, knowledge storage is often less emphasized. The primary focus lies in the direct application of knowledge within construction and operational activities, where practical implementation takes precedence. Additionally, in dynamic project environments characterized by frequent changes and adaptations, knowledge storage becomes more valuable when integrated directly with knowledge-sharing processes, enabling real-time access and utilization.

The data analysis underscores several key factors influencing the success of KM processes in the MRT CP201 project. As shown in Table 2, clarity of roles and responsibilities emerges with the highest weight value, indicating its central role in ensuring project success. Simultaneously, skills and comprehension levels achieve the highest rating value, highlighting their importance in equipping team members with the necessary competencies. These findings suggest that clarity of roles and responsibilities is the most critical factor, requiring dedicated attention and resource allocation to ensure alignment with project and organizational goals

Table 2 Internal Knowledge Acquisition Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Clarity of Roles and Responsibilities	0.223	1	1	Skill and Comprehension Level	0.899	1
2	Leadership Involvement and Support	0.209	2	2	Skill and Knowledge Matching	0.892	2
3	Skill and Comprehension Level	0.180	3	3	Team Stability	0.870	3
4	Team Stability	0.143	4	4	Leadership Involvement and Support	0.855	4
5	Skill and Knowledge Matching	0.128	5	5	Communication Facilities	0.854	5
6	Communication Facilities	0.117	6	6	Clarity of Roles and Responsibilities	0.834	6

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.223	0.834	0.186	1
2	Leadership Involvement and Support	0.209	0.855	0.179	2
3	Skill and Comprehension Level	0.180	0.899	0.161	3
4	Team Stability	0.143	0.870	0.125	4
5	Skill and Knowledge Matching	0.128	0.892	0.114	5
6	Communication Facilities	0.117	0.854	0.100	6

Table 3 highlights that the cooperation and partnership sub-criteria hold the highest weight value, while external regulations and policies achieve the highest rating value. These findings underscore the importance of both factors in influencing project success and organizational performance. Cooperation and partnerships play a critical role in facilitating smooth collaboration among stakeholders, particularly in JO construction projects where effective communication and mutual support are essential for technology transfer. Meanwhile, external regulations and policies reflect the need to navigate compliance requirements and align project objectives with regulatory frameworks. The analysis further reveals that cooperation and partnerships have the highest score value, emphasizing their pivotal role in ensuring stakeholder alignment and fostering successful project outcomes. Therefore, targeted attention and resource allocation toward strengthening partnerships and addressing regulatory challenges are essential for achieving project goals and enhancing collaboration across all levels.

Table 3 External Knowledge Acquisition Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Cooperation and Partnership	0.232	1	1	External Regulations and Policies	0.944	1
2	Changes in Technology and Industry Standards	0.227	2	2	Changes in Technology and Industry Standards	0.910	2
3	Limited Access to Resources	0.160	3	3	Stakeholder Policy	0.901	3
4	Stakeholder Policy	0.154	4	4	Uncertain Market Conditions	0.898	4
5	External Regulations and Policies	0.116	5	5	Cooperation and Partnership	0.896	5
6	Uncertain Market Conditions	0.110	6	6	Limited Access to Resources	0.882	6

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Cooperation and Partnership	0.232	0.896	0.208	1
2	Changes in Technology and Industry Standards	0.227	0.910	0.206	2
3	Limited Access to Resources	0.160	0.882	0.141	3
4	Stakeholder Policy	0.154	0.901	0.139	4
5	External Regulations and Policies	0.116	0.944	0.110	5
6	Uncertain Market Conditions	0.110	0.898	0.099	6

Table 4 reveals that both the highest weight and rating values are associated with the clarity of roles and responsibilities sub-criteria. This indicates that these factors play a crucial role in determining which aspects are most significant and have a major impact on the project's or organizational goals' success. As such, these factors demand greater attention and allocation of resources to ensure that roles and responsibilities are clearly defined and understood by all stakeholders. The analysis confirms that the clarity of roles and responsibilities sub-criteria hold the highest score value, emphasizing their critical importance for achieving successful project outcomes.

Table 4 Internal Knowledge Usage Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Clarity of Roles and Responsibilities	0.349	1	1	Clarity of Roles and Responsibilities	0.849	1
2	Adequate Training	0.208	2	2	Adequate Training	0.832	2

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
3	Effectiveness of Organizational Policies	0.184	3	3	Incentives for Knowledge Sharing	0.826	3
4	Incentives for Knowledge Sharing	0.155	4	4	Effectiveness of Organizational Policies	0.815	4
5	Resistance to Change	0.105	5	5	Resistance to Change	0.767	5

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.349	0.85	0.296	1
2	Adequate Training	0.208	0.83	0.173	2
3	Effectiveness of Organizational Policies	0.284	0.82	0.150	3
4	Incentives for Knowledge Sharing	0.155	0.83	0.128	4
5	Resistance to Change	0.105	0.77	0.080	5

Table 5 reveals that the highest weight value is attributed to the uncertain market conditions sub-criteria, while the highest rating value is found in the cooperation and partnership sub-criteria. The significance of the highest scoring value lies in its ability to determine which factors are considered most crucial and have a substantial impact on the project's or organizational goals' success. Consequently, these factors demand greater attention and appropriate resource allocation. The analysis highlights that the uncertain market conditions sub-criteria hold the highest score value, indicating the need for strategic focus to navigate and manage market uncertainties effectively for project success.

Table 5 External Knowledge Usage Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Uncertain Market Conditions	0.221	1	1	Cooperation and Partnership	0.913	1
2	Limited Access to Resources	0.201	2	2	Limited Access to Resources	0.912	2
3	Cooperation and Partnership	0.197	3	3	External Regulations and Policies	0.879	3

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
4	External Regulations and Policies	0.142	4	4	Uncertain Market Conditions	0.848	4
5	Stakeholder Policy	0.126	5	5	Changes in Technology and Industry Standards	0.723	5
6	Changes in Technology and Industry Standards	0.113	6	6	Stakeholder Policy		6

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Uncertain Market Conditions	0.221	0.872	0.192	1
2	Limited Access to Resources	0.201	0.912	0.183	2
3	Cooperation and Partnership	0.197	0.913	0.180	3
4	External Regulations and Policies	0.142	0.879	0.125	4
5	Changes in Technology and Industry Standards	0.113	0.848	0.096	5
6	Stakeholder Policy	0.126	0.723	0.091	6

Tale 6 demonstrates that the highest weight value is attributed to the clarity of roles and responsibilities sub-criteria, while the highest rating value is found in the knowledge-sharing culture sub-criteria. The significance of the highest scoring value lies in its role in identifying the factors that are most crucial and have a substantial impact on the project's or organizational objectives. As a result, these factors necessitate focused attention and resource allocation to ensure the project's success. The analysis indicates that the clarity of roles and responsibilities sub-criterion holds the highest score value, underlining its importance in guiding effective project management and organizational alignment.

Table 6 Internal Knowledge-Sharing Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Clarity of Roles and Responsibilities	0.262	1	1	Knowledge Sharing Culture	0.960	1
2	Knowledge Sharing Culture	0.200	2	2	Knowledge-Task Match	0.957	2
3	Adequate Training	0.169	3	3	Clarity of Roles and Responsibilities	0.952	3
4	Knowledge-Task Match	0.147	4	4	Adequate Training	0.831	4

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
5	Skill and Knowledge Matching	0.116	5	5	Skill and Knowledge Matching	0.828	5
6	Incentives for Knowledge Sharing	0.106	6	6	Incentives for Knowledge Sharing	0.799	6

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.262	0.952	0.249	1
2	Knowledge Sharing Culture	0.200	0.960	0.192	2
3	Knowledge-Task Match	0.147	0.957	0.141	3
4	Adequate Training	0.169	0.831	0.141	4
5	Skill and Knowledge Matching	0.116	0.828	0.096	5
6	Incentives for Knowledge Sharing	0.106	0.799	0.084	6

Table 7 highlights that the highest weight value is assigned to the cooperation and partnership sub-criteria, while the highest rating value is observed in the geographical or regional barriers sub-criteria. The importance of the highest scoring value lies in its ability to help determine which factors are the most critical and have the greatest impact on achieving the project's or organizational goals. Consequently, these factors demand increased focus and resource allocation to ensure project success. The analysis reveals that the cooperation and partnership sub-criterion carries the highest score value, underscoring its significance in fostering collaboration and overcoming potential barriers in JO projects.

Table 7 External Knowledge-Sharing Data Analysis

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
1	Cooperation and Partnership	0.265	1	1	Geographic or Regional Barriers	0.920	1
2	External Regulations and Policies	0.218	2	2	Security and Confidentiality Risks	0.914	2
3	Changes in Technology and Industry Standards	0.149	3	3	Cooperation and Partnership	0.903	3
4	Limited Access to Resources	0.148	4	4	External Regulations and Policies	0.892	4

Analytical Hierarchy Process (AHP)				Fuzzy Sets			
No	**Sub Criteria**	**Weight (Wsi)**	**Rank**	**No**	**Sub Criteria**	**Rating (Rai)**	**Rank**
5	Security and Confidentiality Risks	0.122	5	5	Changes in Technology and Industry Standards	0.890	5
6	Geographic or Regional Barriers	0.098	6	6	Limited Access to Resources	0.870	6

Simple Additive Weighting (SAW)					
No.	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Cooperation and Partnership	0.265	0.903	0.239	1
2	External Regulations and Policies	0.218	0.892	0.194	2
3	Changes in Technology and Industry Standards	0.149	0.890	0.133	3
4	Limited Access to Resources	0.148	0.870	0.129	4
5	Security and Confidentiality Risks	0.122	0.914	0.112	5
6	Geographic or Regional Barriers	0.098	0.920	0.090	6

In the AHP analysis, the highest weight value indicates the relative importance of the related factors (Saaty, 1980). A high weight value in KM processes highlights the significant influence of a factor on the success of knowledge acquisition, usage, or sharing within the project. This means that the factors with the highest weight values must be prioritized and given sufficient attention to ensure the effective implementation of KM strategies. Properly addressing these factors enhances the overall KM processes, ultimately contributing to the project's success. The sub-criteria with the highest weight values for each criterion are summarized in Table 8.

Table 8 Summary of Highest AHP Data Analysis Values

No	Criteria	Sub Criteria	Weight (Wsi)	Rank
1	Knowledge Acquisition			
	Sub Criteria Internal	Clarity of Roles and Responsibilities	0.180	1
	Sub Criteria External	Cooperation and Partnership	0.232	1
2	Use of Knowledge			
	Sub Criteria Internal	Clarity of Roles and Responsibilities	0.349	1
	Sub Criteria External	Uncertain Market Conditions	0.221	1
3	Knowledge Sharing			
	Sub Criteria Internal	Clarity of Roles and Responsibilities	0.262	1
	Sub Criteria External	Cooperation and Partnership	0.265	1

The highest rating value in Fuzzy Set analysis indicates the strongest membership level of a variable within a given fuzzy set, signifying its high relevance or compatibility with the specified conditions or criteria. A higher rating value means that the variable significantly contributes to

the success of the KM processes in the project (Klir & Yuan, 1995). In this analysis, variables with the highest rating values are identified as having the most substantial impact on KM and technology transfer. Such variables should be prioritized in project planning and implementation to ensure optimal outcomes.

Literature often establishes a rating threshold of 0.8 to signify a strong membership level, suggesting a significant contribution to the process (Ross, 2010). In Table 9, two sub-criteria—change resistance and stakeholder policies—fall below this 0.8 threshold (indicated in bold-italic). Change resistance is often a situational variable and can be mitigated through targeted interventions, making it less of a universal barrier to technology transfer (Hassan, 2018). On the other hand, stakeholder policies, though important, vary widely and may not always have a direct or immediate influence on the success of technology transfer (Ribbers, 2009). These factors, while noteworthy, require contextual consideration rather than being seen as constant barriers.

Table 9 Summary of Fuzzy Set Data Analysis

No	Criteria		Sub Criteria	Rating (Rsi)
1	Knowledge Acquisition	Internal	Clarity of Roles and Responsibilities	0.83
			Leadership Involvement and Support	0.86
			Skill and Comprehension Level	0.90
			Team Stability	0.87
			Skill and Knowledge Matching	0.89
			Communication Facilities	0.85
		External	Cooperation and Partnership	0.90
			Changes in Technology and Industry Standards	0.91
			Limited Access to Resources	0.88
			Stakeholder Policy	0.90
			External Regulations and Policies	0.94
			Uncertain Market Conditions	0.90
2	Knowledge Usage	Internal	Clarity of Roles and Responsibilities	0.85
			Adequate Training	0.83
			Effectiveness of Organizational Policies	0.82
			Incentives for Knowledge Sharing	0.83
			Resistance to Change	0.77
		External	Uncertain Market Conditions	0.87
			Limited Access to Resources	0.91
			Cooperation and Partnership	0.91
			External Regulations and Policies	0.88
			Stakeholder Policy	0.85
			Changes in Technology and Industry Standards	0.72
3	Knowledge Sharing	Internal	Clarity of Roles and Responsibilities	0.95
			Knowledge Sharing Culture	0.96
			Adequate Training	0.96
			Knowledge-Task Match	0.83
			Skill and Knowledge Matching	0.83
			Incentives for Knowledge Sharing	0.80
		External	Cooperation and Partnership	0.90
			External Regulations and Policies	0.89
			Changes in Technology and Industry Standards	0.89
			Limited Access to Resources	0.87
			Security and Confidentiality Risks	0.91
			Geographic or Regional Barriers	0.92

The highest scoring value in scoring analysis reflects a variable's highest level of excellence or suitability to the established criteria (Malczewski & Jacek, 1999). A high score indicates that the variable is the most effective or best suited to the project's goals or standards. In other words, the higher the score, the more significant the variable's contribution to the success of KM processes within the project.

In the context of KM and technology transfer, variables with the highest scores are deemed to be the most critical or influential factors. These variables should be prioritized to enhance project success, ensuring that the technology transfer process aligns effectively with the project's objectives.

The summary of Tables 10 and 11 provides detailed results of the scoring analysis, identifying which variables score highest, thus offering insights into the most crucial factors driving successful KM and technology transfer in the project. These results help in pinpointing key areas where attention and resources should be concentrated to ensure optimal project outcomes.

Table 10 Summary of Scoring Data Analysis Internal Factor

Internal Knowledge Acquisition Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.223	0.834	0.186	1
2	Leadership Involvement and Support	0.209	0.855	0.179	2
3	Skill and Comprehension Level	0.180	0.899	0.161	3
4	Team Stability	0.143	0.870	0.125	4
5	Skill and Knowledge Matching	0.128	0.892	0.114	5
6	Communication Facilities	0.117	0.854	0.100	6
Internal Knowledge Usage Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.349	0.849	0.296	1
2	Adequate Training	0.208	0.832	0.173	2
3	Effectiveness of Organizational Policies	0.184	0.815	0.150	3
4	Incentives for Knowledge Sharing	0.155	0.826	0.128	4
5	Resistance to Change	0.105	0.767	0.080	5
Internal Knowledge-Sharing Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Clarity of Roles and Responsibilities	0.262	0.952	0.249	1
2	Knowledge Sharing Culture	0.200	0.960	0.192	2
3	Adequate Training	0.147	0.957	0.141	3
4	Knowledge-Task Match	0.169	0.831	0.141	4
5	Skill and Knowledge Matching	0.116	0.828	0.096	5
6	Incentives for Knowledge Sharing	0.106	0.799	0.084	6

Table 11 Summary of Scoring Data Analysis External Factor

External Knowledge Acquisition Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Cooperation and Partnership	0.232	0.896	0.208	1
2	Changes in Technology and Industry Standards	0.227	0.910	0.206	2
3	Limited Access to Resources	0.160	0.882	0.141	3
4	Stakeholder Policy	0.154	0.901	0.139	4
5	External Regulations and Policies	0.116	0.944	0.110	5
6	Uncertain Market Conditions	0.110	0.898	0.099	6
External Knowledge Usage Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Uncertain Market Conditions	0.221	0.872	0.192	1
2	Limited Access to Resources	0.201	0.912	0.183	2
3	Cooperation and Partnership	0.197	0.913	0.180	3
4	External Regulations and Policies	0.142	0.879	0.125	4
5	Stakeholder Policy	0.113	0.848	0.096	5
6	Changes in Technology and Industry Standards	0.126	0.723	0.091	6
External Knowledge Sharing Data Analysis					
No	**Sub Criteria**	**Weight (Wsi)**	**Rating (Rsi)**	**Score (Wsi x Rsi)**	**Rank**
1	Cooperation and Partnership	0.265	0.903	0.239	1
2	External Regulations and Policies	0.218	0.892	0.194	2
3	Changes in Technology and Industry Standards	0.149	0.890	0.133	3
4	Limited Access to Resources	0.148	0.870	0.129	4
5	Security and Confidentiality Risks	0.122	0.914	0.112	5
6	Geographic or Regional Barriers	0.098	0.920	0.090	6

The highest scores in Tables 10 and 11 pinpoint the most significant criteria or sub-criteria for successful KM. For internal knowledge acquisition, the key factors are "Clarity of Roles and Responsibilities" and "Leadership Involvement and Support," underscoring the need for defined roles and solid leadership. Externally, "Cooperation and Partnership" and "Changes in Technology and Industry Standards" are paramount, highlighting the importance of collaboration and keeping pace with industry advancements.

In terms of knowledge usage, "Clarity of Roles and Responsibilities" and "Adequate Training" rank as top internal factors, stressing the need for well-defined roles and sufficient training. Externally, "Uncertain Market Conditions" and "Limited Access to Resources" emerge as main challenges, calling for strategies to navigate market fluctuations and address resource limitations.

For knowledge sharing, "Clarity of Roles and Responsibilities" and "Knowledge Sharing Culture" are vital internally, suggesting the necessity of clear roles alongside a strong knowledge-

sharing ethos. Externally, "Cooperation and Partnership" and "External Regulations and Policies" are crucial, reflecting the need for partnerships and regulatory compliance.

These findings resonate with previous research on the significance of organizational clarity, leadership backing, and collaboration in KM (Dalkir, 2013; Nonaka & Takeuchi, 1995). Challenges such as market conditions and resource access align with the insights of Gboney (2009), while the emphasis on training and organizational policies echoes Czabke's (2008) findings.

The robustness of these results stems from the rigorous application of AHP, fuzzy sets, and scoring methods, ensuring a reliable analysis. Expert validation was further achieved through feedback from experienced professionals in project management and engineering, confirming the findings' practical relevance. Experts included a Track and Bridge Maintenance Manager at PT Kereta Api Indonesia with 15 years of experience and a PhD in Project Management, a Vice President of Construction at PT Integrasi Transit Jakarta with a Master's in Project Management and 15 years of experience, and a Deputy Project Director of the LRT Jakarta Project with similar qualifications.

The scoring analysis offers a sound basis for developing strategies to address technology transfer challenges in the project. By focusing on high-scoring factors, such as clarity in roles, leadership support, and training, the project team can craft strategies that emphasize role definition, strengthen leadership involvement, and expand training initiatives to support effective technology transfer.

Furthermore, the scoring analysis helps prioritize and allocate resources effectively during strategy implementation. Factors with high scores can be prioritized for immediate action, while those with lower scores may be addressed selectively or with alternate methods. Thus, the scoring analysis provides a solid foundation for developing focused strategies to enhance technology transfer in the project, which can contribute to successful implementation and improved project performance. The SECI model (Socialization, Externalization, Combination, and Internalization), proposed by Nonaka and Takeuchi (1995), will guide the development of these strategies.

The SECI model is a dynamic framework for managing knowledge within organizations. It's particularly suited to technology transfer in JO construction projects, as it incorporates four modes of knowledge conversion. In the Socialization stage, tacit knowledge is shared through direct interaction and shared experiences, essential in project settings. The Combination stage integrates different pieces of explicit knowledge to form new, cohesive knowledge. For the MRT CP201 project, this might involve collating project documentation, reports, and case studies into a structured KM system. Internalization is where explicit knowledge is reabsorbed as tacit knowledge through practice and repeated application, enabling team members to internalize new skills and information effectively.

The SECI model ideal for JO projects as it addresses both tacit and explicit knowledge, ensuring comprehensive knowledge use and adaptability to evolving project requirements. Its collaborative approach encourages teamwork and collective problem-solving, fostering a culture of knowledge sharing through socialization and externalization. Meanwhile, the combination and internalization phases standardize best practices and support continuous learning—vital for keeping performance high and adjusting to new technologies. The SECI model has shown success in other developing countries, such as India's Delhi Metro Rail Corporation (DMRC) and South Africa's Gautrain Rapid Rail Link, which used structured knowledge-sharing and development programs to facilitate effective technology transfer.

for the MRT CP201 project in Indonesia, the SECI model's implementation for internal knowledge acquisition, focusing on role clarity, could be particularly impactful. Here's an outline of the strategy across each SECI stage:

1. Socialization: Focus on mentoring and coaching (Clutterbuck, 2004), experiential training (Kolb, 2014), collaborative activities (Forsyth, 2018), social interaction (Spendolini, 1992) and international benchmarking with engineering peers (Nonaka & Takeuchi, 1995).
2. Externalization: This involves documenting roles and responsibilities (Harrington, 1995), creating interview transcripts (Rubin & Rubin, 2011), and preparing detailed reports and guidelines (Hartley, 2004).
3. Combination: Includes knowledge integration (Alavi & Leidner, 2001), conducting targeted training and workshops (Salas & Cannon-Bowers, 2001) and distributing knowledge systematically (Davenport & Prusak, 1998).
4. Internalization: Emphasizes personal learning (Cross, 2007), assessment and feedback (Armstrong, 2006), advanced mentoring (Aguinis, 2013), performance appraisal (Broadwell, 1980) and train-the-trainer programs (Nonaka & Takeuchi, 1995).

Adapting these methods for the Indonesian context, especially the CP201 MRT project, could drive effective technology transfer. Incorporating mentoring and coaching from India's DMRC model can enhance tacit knowledge sharing, while role documentation as implemented in projects like Rio's Olympic Park would strengthen clarity and accountability. Similarly, continuous learning and assessment programs inspired by South Africa's Gautrain project could support knowledge retention and effective internalization of new skills.

By blending local insights with proven global practices, this approach offers a robust and adaptive KM strategy tailored to the Indonesian construction context. This model can address unique challenges, such as diverse technological readiness and resource limitations, ensuring an effective approach to KM and technology transfer.

5. CONCLUSION

The study concludes that KM plays a pivotal role in facilitating technology transfer within organizations, particularly through processes of knowledge acquisition, usage, and sharing. Internally, the clarity of roles and responsibilities emerged as critical for effective technology transfer, ensuring that team members understand their tasks and responsibilities. Externally, cooperation and partnerships were identified as vital for knowledge acquisition and sharing, fostering collaboration between stakeholders and enhancing project outcomes. Additionally, uncertain market conditions significantly influence knowledge utilization, emphasizing the need for adaptive strategies to address external challenges. While knowledge storage holds less importance in dynamic environments, it becomes impactful when directly integrated with sharing practices, ensuring practical application.

To achieve effective technology transfer in the MRT CP201 project, strategies should focus on these critical sub-criteria—role clarity, partnerships, and adaptability. Applying Nonaka and Takeuchi's SECI model, which includes mentoring, documentation, knowledge integration, and continuous learning, can further strengthen knowledge transfer processes and improve project performance.

Future research is recommended to replicate this study in other contexts, particularly in regions like Nigeria's South-East, South-West, and South-South. This would provide a comprehensive understanding of infrastructure challenges, enabling the development of tailored policies to address regional-specific risks and improve project outcomes. By prioritizing KM strategies and fostering collaboration, organizations can enhance knowledge flow, address critical challenges, and achieve sustainable growth in complex projects.

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IMPACT OF LOGISTICS FACTORS ON PROCUREMENT OF CONSTRUCTION MATERIALS IN LOKOJA, KOGI STATE

Muhammaed Etudaiye Ohida[1*], Isa Imam[1], and Araoye Olarinkoye Ajiboye[1]

[1]*Confluence University of Science and Technology, Osara, Kogi State, Nigeria*
[2]*Federal University of Technology Minna, Nigeria*

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ABSTRACT

This study investigates the influence of logistics factors on the procurement of construction materials in Lokoja, Kogi State, aiming to identify and rank the critical elements affecting material procurement in building projects. A total of 250 questionnaires were distributed across nineteen neighborhoods in Lokoja using a random sampling technique. Data were analyzed using descriptive statistics, while the T-test assessed the significance of identified logistics factors. The findings revealed that seventeen logistics factors influence material procurement, with seven factors emerging as the most significant: on-time delivery, transportation challenges, material misdelivery, delivery inaccuracies, order processing, storage capacity limitations, and ineffective information flow. These factors were ranked by their impact on procurement processes, with hypothesis testing confirming a statistically significant relationship between logistics factors and material procurement efficiency. The study concludes that effective management of key logistics factors is essential to avoid cost overruns, delays, and material wastage. It recommends that project managers prioritize better coordination among stakeholders to address logistics-related challenges, ensuring materials are delivered efficiently and on time.

Keywords: Logistics factor; Procurements; On time delivery; Information flows; Lokoja

1. INTRODUCTION

The construction sector plays a vital role in the global economy, employing over 100 million people and contributing significantly to the gross domestic product (GDP) of many nations. According to the Global Construction Market Prospect (2021), the industry accounts for approximately 15% of the world's GDP, with industrialized nations contributing 5% and developing countries contributing 8%. In Nigeria, a developing economy, the construction sector has seen notable growth in its GDP share. The National Bureau of Statistics (NBS, 2022) reports that the construction sector contributes 10% to Nigeria's GDP. Additionally, the industry recorded growth rates of 1.31% in Q4 2019, 3.18% in Q1 2019, and 1.69% in Q1 2020.

Despite this significant contribution, inefficiencies such as material waste, poor logistics systems, and supply chain delays continue to hinder the construction sector's overall productivity, particularly in developing countries like Nigeria. Addressing these issues through improved procurement and logistics systems is essential for enhancing overall productivity and efficiency.

Over time, researchers have highlighted numerous internal and external factors that influence construction projects, particularly in building construction. These factors include inadequate planning, material shortages, limited on-site availability, and insufficient participation in decision-making processes (Alaghbari et al., 2019; Momade & Hainin, 2018; Bekr, 2017).

*Corresponding author's email: ohidamuhammedetudaiye@gmail.com
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In recent studies, greater attention has been directed toward the role of logistics in construction project performance. Scholars such as Ohida et al. (2022), Umar (2022), Kabir (2023), Tarun et al. (2016), Chen et al. (2014), Fei et al. (2014), and Spillane et al. (2011) have examined how challenges like material storage, transportation delays, on-site handling inefficiencies, material misdelivery, and late deliveries adversely impact project outcomes.

Material procurement, which involves the selection, ordering, invoicing, payment, and delivery of construction materials, is a fundamental aspect of construction projects. Logistics, within the procurement process, ensures that materials are delivered on time, in good condition, and in a cost-effective manner. The logistics process ensures that materials are delivered efficiently on time, and in good condition, while minimizing costs and delays. Eze et al. (2020) emphasize that inefficient procurement processes are a primary cause of material waste and project delays, findings that align with earlier research by Aibinu and Odeyinka (2006).

Several logistics-related challenges affect material procurement efficiency. Key issues include vendor selection, transportation delays, poor material quality, slow decision-making processes, inaccurate forecasting, and communication gaps between contractors and suppliers. Additional barriers, such as limited road infrastructure and inadequate supply chain expertise, further exacerbate inefficiencies (Tunji-Olayeni et al., 2017; Simon-Eigbe et al., 2022; Kiromo, 2015; Shakantu et al., 2003; Almohsen & Ruwanpur, 2011; Fei et al., 2014; Susanne & Walther, 2017; Gunsanmi, 2013).

Lokoja, the capital of Kogi State, provides a pertinent case for exploring these challenges. The city's construction sector faces a variety of logistical obstacles, including fragmented communication, inconsistent material quality, order processing inefficiencies, and transportation delays. As a central hub connecting Nigeria's northern and southern regions, Lokoja's strategic importance is undermined by its insufficient transportation infrastructure, creating bottlenecks in material supply chains.

To address these concerns, effective management and coordination of logistics factors are essential for improving procurement efficiency and overall productivity in Lokoja's construction sector. A Empirical studies, including those by Tunji-Olayeni et al. (2017), demonstrate that challenges such as material quality issues, extended wait times, and transportation delays are significant contributors to procurement inefficiencies. Addressing these constraints can unlock greater project efficiency. Against this backdrop, this study employs a survey-based approach to analyze how logistics factors impact the procurement of construction materials in Lokoja, identifying key areas for improvement.

2. LITERATURE REVIEWS

2.1. Theoretical Review

To effectively understand the impact of logistics issues on the procurement of construction materials, it is essential to apply relevant management theories. One of the most widely accepted theories in this context is the Theory of Constraints (TOC). Introduced by Goldratt and Cox (1984), TOC suggests that any manageable system is constrained by a small set of limiting factors that restrict its ability to achieve intended goals. In the procurement context, these constraints often hinder the efficiency and effectiveness of material procurement processes.

According to TOC, a constraint refers to any factor that obstructs a system's ability to meet its objectives. Within the construction industry, such constraints include issues that disrupt the procurement system's efficiency. Empirical studies, including those by Tunji-Olayeni et al. (2017), demonstrate that challenges such as material quality issues, extended wait times, and

transportation delays are significant contributors to procurement inefficiencies. Addressing these constraints can unlock greater project efficiency.

Another valuable theoretical framework is the Transaction Cost Economic (TCE) theory, originally proposed by Coase (1937). TCE posits that the total cost of completing a project includes all related transaction costs, such as ordering, planning, procurement, tendering, and addressing delays. In the construction sector, these transaction costs encompass not only direct material expenses but also indirect costs, such as warehousing inefficiencies or late deliveries. Recent studies, such as Abdullateef et al. (2022), highlight how challenges in warehousing and transportation systems drive up procurement costs and delay project timelines.

The Contingency Theory, introduced by Fiedler in 1967, further underpins the study. This theory argues that there is no universally optimal way to manage organizations or processes. Instead, the effectiveness of any approach depends on specific internal and external conditions. In the procurement process, internal factors like budget constraints and quality standards interact with external factors such as supplier reliability and delivery efficiency, directly influencing procurement decisions.

Another framework frequently applied in project management research is Agency Theory, originally introduced by Berle and Means (1932). This theory examines conflicts of interest that arise when one party (the "agent") acts on behalf of another party (the "principal"). In construction projects, the site owner assumes the role of the principal, while the contractor functions as the agent tasked with executing the project. Conflicts occur when the agent's actions do not align with the principal's objectives, leading to inefficiencies. For example, Eze et al. (2020) report that misalignment in resource use often leads to delays and increased costs in construction projects.

2.2. Empirical Review

2.2.1. Assessing the Impact of Logistics Factors on Construction Project Performance

Chen et al. (2014) define the construction logistics process as involving several activities, including the supply of labor, machinery, and equipment, as well as plan control, data processing, material management on-site, infrastructure development, site arrangement, physical distribution, and information exchange. Empirical studies have demonstrated that improved logistics management reduces indirect costs associated with material handling and delivery, while also minimizing system inefficiencies caused by low productivity (Kabir, 2023; Ohida et al., 2022).

Extensive research highlights the significant impact of logistics factors on construction project performance. For instance, Simon-Eigbe et al. (2022) investigated building construction in Abuja and identified key challenges, including design changes, rising material costs, contract variations, slow decision-making, delayed variation orders, resource shortages, lack of skilled personnel, and inadequate coordination. These factors were found to be the primary contributors to project delays and inefficiencies.

In a study focusing on Canadian construction, Almohsen and Ruwanpur (2011) explored the role of modern technologies, particularly mobile applications, in logistics management. The study received strong positive feedback from industry professionals, who reported improved communication among stakeholders and enhanced efficiency in managing logistics. Similarly, Chen et al. (2014) analyzed logistical practices in U.S. engineering projects and emphasized the need for specialized distribution management teams. Their findings also identified research gaps, including insufficient exploration of procurement administration, order processing, transportation challenges, and information flows.

Rabiu (2023) examined the influence of logistics activities on construction project delivery in Nasarawa State. The study identified critical logistics activities, such as planning and risk assessment, sourcing and procurement, warehousing, and transportation management, as significant contributors to project success. High transportation costs emerged as a major obstacle to efficient logistics operations in the Nasarawa construction sector.

2.2.2. Influence of Material Procurement on Construction Project Performance

Material procurement plays a pivotal role in construction logistics, involving the strategic selection of suppliers to ensure that materials are delivered at the right price, time, quality, quantity, and source (Umar, 2022). Timely delivery of procured materials is a vital indicator of supply chain efficiency, contributing to client satisfaction and overall project success. As noted by Dalin and Kaptzan (2021), clients often evaluate procurement success based on delivery timeliness.

Delays in material delivery can have serious consequences. Emeka (2016) emphasizes that late deliveries disrupt project activities, leading to potential delays in overall project completion. Similarly, Van der Rhee et al. (2009) highlight that timely material delivery is a key factor in supplier selection, playing a critical role in ensuring construction project efficiency.

Olugbenga et al. (2013) compared various procurement methods in Nigeria and observed that traditional approaches remain the most commonly used, despite being less efficient than modern systems, such as construction management frameworks. Sung-Hoon and Umuhoza (2023) reached a similar conclusion in their study on Rwandan building projects, highlighting the positive influence of construction management systems on project quality and scope.

Anyanwu et al. (2021) investigated effective procurement tools for construction projects in Imo State, Nigeria. Their findings emphasized the importance of procurement specialists in ensuring high project delivery quality. Effective estimation and tendering practices were identified as critical factors for successful outcomes.

Muhammad (2022) explored material procurement risks in Abuja's construction industry. The study revealed that rigid design specifications, frequent order changes, inflation, and bad debt were major risks adversely affecting project cost, time, and quality performance.

2.2.3. Logistics Factors Influencing Building Materials Procurement

Several logistics-related factors significantly affect material procurement for construction projects. Transportation is particularly critical, as most construction materials are sourced externally rather than produced on-site. Transportation costs can account for 4-10% of the product's selling price and 39-58% of total logistics costs (Coyle et al., 1996). However, detailed cost breakdowns are rarely provided (Shakantu, 2003).

Material handling equipment also plays a significant role by ensuring the smooth movement of materials, minimizing manual labor, and improving construction site productivity.

Tunji-Olayeni et al. (2017) identified key logistics challenges in Nigeria, including low-quality materials, extended waiting times, inaccurate activity forecasting, inefficient transportation, and delayed material deliveries, all of which negatively affect construction site productivity.

In Nairobi’s construction industry, Kiromo (2015) found that transportation challenges such as road accessibility, depot distances, and site location were major barriers to material delivery, impacting supplier performance. Similarly, Tarun et al. (2016) categorized logistics factors into planning, conducting, administering, and closing procurement processes, identifying 38 parameters that influence procurement decisions.

Using Abuja's construction industry as a case study, Abdullateef et al. (2022) emphasized that transportation inefficiencies, warehousing problems, delivery inaccuracies, and poor forecasting were the most significant logistics issues affecting material procurement.

2.3. Theoretical Framework

This investigation is grounded in the concept of constraints, particularly in understanding how logistics factors influence the procurement of construction materials. The study hypothesizes that procurement processes are affected by multiple logistics factors, including order processing, transportation issues, delivery inaccuracies, and poor information flow. Each factor serves as a potential bottleneck, reducing the procurement system's ability to source, manage, and deliver materials efficiently. Inefficient procurement practices can result in cost overruns, project delays, and, in extreme cases, project abandonment.

3. RESEARCH METHOD

The data collection process took place over two days in each of the nineteen neighborhoods of Lokoja. With the help of three field assistants, data was collected to investigate how logistics components influence material procurement processes in construction projects.

The study population consists of construction professionals in Lokoja, Kogi State, including site managers, laborers, civil engineers, architects, surveyors, builders, contractors, project managers, and supervisors. To ensure fair representation, a simple random sampling method was adopted, distributing 250 questionnaires across the nineteen neighborhoods of Lokoja.

The questionnaire was structured into two sections. The first section gathered socioeconomic and demographic details about construction professionals, while the second focused on seventeen variables related to the influence of logistics components on material procurement. A five-point Likert scale was used to measure responses, where 1 represented "strongly disagree" and 5 represented "strongly agree." This scale provided a simple yet effective approach to capturing the perceptions and experiences of construction professionals in Lokoja.

To validate the internal consistency of the questionnaire, a pilot survey was conducted, where 10% of the total questionnaires were distributed. Respondents rated their level of agreement on logistics components influencing material procurement. Cronbach's alpha testing was performed in SPSS using a two-tailed hypothesis approach, ensuring the reliability of the instrument. Table 1 presents the pilot survey results, with Cronbach's alpha values ranging from 0.75 to 0.88. These values confirm strong internal consistency, as values between 0.70 and 0.80 are considered acceptable, while values above 0.80 demonstrate high reliability, according to Cho (2016).

Table 1 Cronbach Alpha Results

Variable	Cronbach's Alpha	Interpretation
On-time delivery	0.87	Good
Transportation challenges	0.83	Good
Delivering material to wrong location	0.78	Acceptable
Delivery inaccuracy	0.80	Good
Order processing	0.82	Good
Adequate storages for procured materials	0.84	Good
Information flows	0.86	Good
Quality of the procured material	0.85	Good
Variation in material	0.75	Acceptable
Poor coordination of logistics activities	0.77	Acceptable

Variable	Cronbach's Alpha	Interpretation
Effective estimation and tendering process	0.88	Good
Distance constraint from the suppliers to site	0.79	Acceptable
Longer time for procured materials received	0.81	Good
Difficulties in transporting small quantities	0.76	Acceptable
Inconsistency in order place	0.78	Acceptable
Poor administration of the procurements	0.83	Good
Forecasting construction activity period	0.85	Good

Source: Authors' Survey (2023)

Due to the high internal consistency demonstrated in the pilot survey, the selected research variables were used to finalize the questionnaire, which was then distributed among construction professionals in Lokoja.

Descriptive statistical tools such as frequency distributions, percentages, mean index scores, and ranking were employed to analyze the gathered survey data. Principal Component Factor Analysis was applied to reduce the seventeen logistics factors influencing material procurement into seven key components. These components were then subjected to hypothesis testing using T-test statistics to determine their significance in influencing procurement efficiency.

Lokoja, the capital of Kogi State, served as the study area. The city is located at coordinates 7.8023° N latitude and 6.7333° E longitude, spanning a total land area of 3,180 km² with a population of 195,261, according to the 2006 census (NPC). Lokoja is home to various ethnic groups, including the Oworo, Bassa Nge, Ebira, Igala, and Nupe, as well as minority groups like the Kupa-Nupe, Hausa, Igbo, Edo, and Tiv. The city's tropical wet and dry savanna climate is particularly favorable for construction activities, as high temperatures accelerate the drying of cement mortar, enhancing on-site productivity.

Lokoja's economy is bolstered by major markets, including the Kpata market, the old market, and the international market, as well as prominent institutions like the Federal University Lokoja and Kogi State Polytechnic. The combination of growing economic opportunities and the presence of higher education institutions has driven migration to Lokoja, increasing the demand for residential and commercial construction projects. Figure 1 illustrates the map of Kogi State, highlighting Lokoja as the study area.

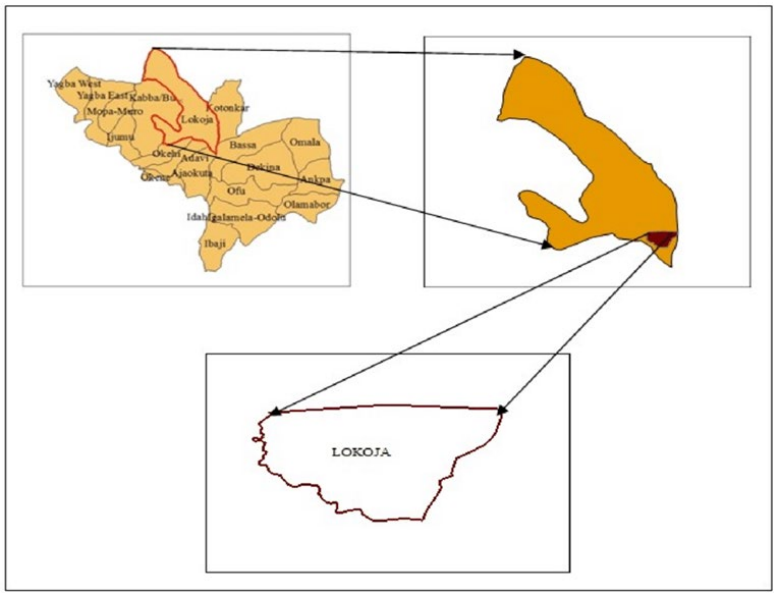

Figure 1 Map of Kogi State Showing Lokoja (Adopted from Thomas et al. 2019)

4. RESULTS AND DISCUSSION

4.1. Analysis of the Socioeconomic & Demographic Features

The analysis of Table 2 highlights the demographic characteristics of construction professionals surveyed. The majority of respondents (62.7%) were male, while females accounted for 37.3%. Over half of the participants (52.3%) are married, with 42.3% single and 5.4% divorced. In terms of age distribution, the largest group (29.9%) is aged 31-40 years, followed by those aged 20-30 (23.3%). Only 17.8% are under 20 years old. Participants aged 41-50 (11.6%), 51-60 (10.4%), and above 61 (7.0%) accounted for smaller proportions.

Table 2 Socioeconomic and Demographic Variables

S/n	Socioeconomic & Demographic Factor		Frequency	Percentages
1	Gender	Male	151	62.7
		Female	90	37.3
		N	241	100.0
2	Marital Status	Married	126	52.3
		Single	102	42.3
		Divorce	13	5.4
		N	241	100.0
3	Age of the Respondent (in years)	below 20	43	17.8
		20-30	56	23.3
		31-40	72	29.9
		41-50	28	11.6
		51-60	25	10.4
		Above 61	17	7.0
		N	241	100.0
4	Monthly Incomes Earned (in Naira)	Below 30,000	67	27.8
		30,000-90,000	39	16.2
		91,000-150,000	46	19.1
		152,000-211,000	55	22.8
		Above 212,000	34	14.1
		N	241	100.0
5	Educational Qualifications	No formal education	36	14.9
		Primary school Cert	21	8.7
		WAEC	48	19.9
		NCA/ND	49	20.3
		BSc/HND	59	24.5
		Postgraduate Cert	28	11.5
		N	241	100.0
6	Profession at the Site	Labourer	37	15.4
		Site manager	29	12.0
		Civil engineer	41	17.0
		Architects	25	10.4
		Surveyors	19	7.9
		Project manager	23	9.5
		Supervisor	15	6.2
		Contractor	32	13.3
		Builder	22	8.3
		N	241	100.0

S/n	Socioeconomic & Demographic Factor		Frequency	Percentages
7	Years of Experiences	1-5	24	9.9
		6-11	55	22.8
		11-16	52	21.6
		16-21	77	31.9
		Over 22	33	13.6
		N	241	100.0
8	No of Sites Work in the Past	1-10	44	18.3
		11-20	82	34.0
		20-30	61	25.3
		Above 31	54	22.4
		N	241	100.0

Source: Authors Field Survey (2023)

Table 2 further illustrates the income distribution of the surveyed construction professionals. The data show that 27.8% of the professionals earn less than N30,000 per month, while 22.8% earn between N152,000 and N211,000. Additionally, 19.1% of respondents earn between N91,000 and N152,000, while 16.2% earn between N30,000 and N90,000 per month. Only 14.1% of the professionals earn more than N212,000 monthly.

In terms of educational qualifications, the majority of professionals hold a Bachelor of Science (BSc) degree or Higher National Diploma (HND). Around 20.3% possess a National Certificate of Education (NCE) or National Diploma (ND), 19.9% have a West African Examination Council (WAEC) qualification, 14.9% reported having no formal education, 11.5% hold a Postgraduate Certificate, and 8.7% possess only a primary school certificate. This indicates that a substantial proportion of the respondents have attained higher educational qualifications.

Additionally, Table 2 shows the occupational breakdown of the participants: 17.0% are civil engineers, 15.4% are laborers, 13.3% are contractors, 12.0% are site managers, 10.4% are architects, 9.5% are project managers, 8.3% are builders, 7.9% are surveyors, and 6.2% are supervisors.

Regarding experience, 31.9% of professionals have between 16 and 21 years of experience in the construction industry, 22.8% have between 6 and 11 years, and 21.6% have between 11 and 16 years of experience. Meanwhile, 13.6% have more than 22 years of experience, while 9.9% have 1 to 5 years of experience.

In terms of the number of construction sites worked on, Table 2 reveals that most professionals (34.0%) have worked on between 11 and 20 sites, while 25.3% have worked on 20 to 30 sites. About 22.4% have worked on more than 31 sites, and 18.3% have worked on fewer than 10 sites.

4.2. Analysis of the Influence of Logistics Factor on Procurement of Building Construction Materials

The analysis of logistics factors influencing the procurement of building construction materials in Lokoja reveals that on-time delivery ranks as the most important factor. Ensuring timely delivery of materials is critical for reducing delays by 20-30%, thereby enhancing efficiency on construction sites (Bramble and Michael, 2000).

Following this, transportation challenges were ranked second. Transportation plays a vital role in moving procured materials from suppliers to construction sites. Chen et al. (2014) emphasize that efficient transportation is crucial for maintaining project schedules and minimizing disruptions.

However, issues such as incorrect deliveries, which may arise due to poor site descriptions, can significantly increase building project costs.

Delivering materials to the wrong location was ranked third, while delivery inaccuracies were ranked fourth. Both issues can lead to delays, additional costs, and inefficiencies in construction activities. Additionally, the ordering process was ranked fifth. A smooth and effective ordering process—where all required items are delivered on time and correctly—helps prevent disagreements and disruptions, ensuring that project timelines remain on track. Adequate storage for procured materials was ranked sixth. Poor storage facilities can adversely impact construction materials, particularly in environments with fluctuating temperatures, which may cause material degradation.

Finally, information flow and the quality of procured materials were ranked seventh and eighth, respectively. Effective information flow is essential for coordinating procurement activities, ensuring that materials are delivered from suppliers to the construction site on time and as specified. Meanwhile, maintaining material quality ensures consistency, minimizing wastage and rework during construction projects.

Table 3 Influence of Logistics Factor on Material Procurement

S/n	Criterion	Mean Index Score	Rank
1	Poor Order Processing	3.624	5th
2	Transportation Challenges	3.733	2nd
3	Delivering Material to Wrong Location	3.647	3rd
4	On Time Delivery	3.815	1st
5	Adequate Storages for Procured Materials	3.534	6th
6	Quality of the Procured Material	3.412	8th
7	Information Flows	5.510	7th
8	Delivery Inaccuracy	3.703	4th
9	Variation in Material	2.561	10th
10	Poor Coordination of Logistics activities	2.659	9th
11	Effective Estimation and Tendering Process	2.370	12th
12	Distance Constraint from the Suppliers to Site	2.358	13th
13	Longer Time for Procured Materials Received	1.283	16th
14	Difficulties in Transporting Small Quantities	2.418	11th
15	Inconsistency in Order Place	2.371	14th
16	Poor Administration of the Procurement	1.518	15th
17	Forecasting Construction Activity Period	1.280	17th

extraction method: principal component analysis
Source: Authors Contribution (2023)

In addition to the findings in Table 3, poor coordination of logistics activities was ranked ninth. Effective coordination of logistics operations is crucial in construction projects as it involves managing various tasks such as transporting materials from suppliers to construction sites and ensuring that project contract requirements are successfully fulfilled.

Other significant factors include variation in materials (ranked 10th), difficulties in transporting small quantities (ranked 11th), effective estimation and tendering processes (ranked 12th), and distance constraints from suppliers to the site (ranked 13th). These factors contribute to additional costs, time overruns, reduced productivity, and wasted resources, all of which can significantly hinder the success of construction projects.

Moreover, the analysis in Table 3 shows that inconsistency in order placement was ranked 14th, while poor administration of procurement processes was ranked 15th. Delays in receiving

procured materials ranked 16th, while forecasting construction activity periods was ranked 17th. These logistical challenges exacerbate project delays, increase costs, and introduce inefficiencies, highlighting the need for effective management strategies to address logistics-related issues in material procurement.

In conclusion, the Risk Vulnerability Index (RVI) analysis across both tables underscores significant risks related to both project roles and scope performance. Key areas such as end-user value, corporate leadership, and project monitoring/control have emerged as high-risk factors, necessitating focused attention from stakeholders to enhance overall project outcomes, particularly in mass housing infrastructure projects in Northern Nigeria.

4.3. Analysis of the Component Factor Analysis (CPFA)

The CFA analysis initially considered seventeen variables related to logistics challenges affecting material procurement, but only eight variables were extracted based on their statistical significance. These variables include on-time delivery with an eigenvalue of 9.625, transportation challenges at 7.232, delivering materials to the wrong location at 5.171, delivery inaccuracies at 4.994, order processing at 2.963, adequate storage for procured materials at 2.861, and information flows at 1.731. Each of these variables demonstrated a total explained variance greater than the threshold eigenvalue of 1, affirming their relative importance in the analysis. The cumulative variance explained by these factors is 79.8%, indicating that these logistics variables collectively account for a substantial proportion of the challenges associated with material procurement in building projects. The remaining variables, including variation in material, poor coordination of logistics activities, effective estimation and tendering processes, and distance constraints, did not meet the eigenvalue threshold and were excluded from further analysis. Table 4 details the Initial Eigenvalues and the Extraction Sums of Squared Loadings for each component.

Table 4 Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
On time delivery	9.625	30.206	30.206	9.625	30.206	30.206
Transportation Challenges	7.232	10.263	40.469	7.232	10.263	40.469
Delivering material to wrong location	5.171	9.756	50.226	5.171	9.756	50.226
Delivery inaccuracy	4.994	8.285	58.510	4.994	8.8285	58.510
Order processing	2.963	8.024	66.534	2.963	8.024	66.534
Adequate storages for procured materials	2.861	7.173	73.707	2.861	7.173	73.707
Information flows	1.731	6.094	79.801	1.731	6.094	79.801
Quality of the procured material	.622	3.183	82.984			
Variation in material	.553	2.610	85.594			
Poor coordination of logistics activities	.486	2.053	87.647			
Effective estimation and tendering process	.437	2.642	90.289			
Distance constraint from the suppliers to site	.325	2.710	92.999			

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Longer time for procured materials received	.311	2.311	95.310			
Difficulties in transporting small quantities	.285	1.719	97.029			
Inconsistency in order place	.214	1.321	98.350			
Poor administration of the procurements	.189	1.211	99.561			
Forecasting construction activity period	.104	.439	100.000			

Extraction Method: Principal Component Analysis
Sources: Authors Contribution (2023)

4.4. Test of Hypothesis

The hypothesis of this study states: H_0: There is no statistically significant impact of the seven key logistics factors on the procurement of building materials in Lokoja. The results, as presented in Table 5, reveal that all seven logistics factors exhibit statistically significant T-values and P-values well below the 0.05 confidence level, indicating a strong influence on the procurement process. On-time delivery recorded the highest T-value of 45.326 with a P-value of 0.000, confirming its significant contribution to procurement efficiency. Similarly, transportation challenges had a T-value of 29.168 and a P-value of 0.000, reflecting its critical role in ensuring timely material movement to construction sites. The variable delivery inaccuracies was characterized by a T-value of 20.219 and a P-value of 0.000, showing the disruptive effects of incorrect deliveries on project timelines and costs.

For order processing, the analysis revealed a T-value of 18.543 and a P-value of 0.000, further emphasizing the importance of maintaining smooth and accurate ordering systems to prevent procurement delays. Additionally, adequate storage for procured materials showed a T-value of 10.992 and a P-value of 0.000, highlighting the need for proper storage facilities to preserve material quality and minimize wastage. Lastly, information flows yielded a T-value of 6.512 with a P-value of 0.000, demonstrating the essential role of effective communication in coordinating procurement activities and ensuring timely delivery of materials.

Table 5 T-test

	Test Value = 0					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
On time delivery	45.326	238	.000	3..571	3.985	3.443
Transportation challenges	29.168	238	.000	3.324	3.761	3.144
Delivering material to wrong location	24.181	238	.000	3.476	3.321	3.774
Delivery inaccuracy	20.219	238	.000	3.176	2.527	3.569
Order processing	18.543	238	.000	3.238	2.886	3.462
Adequate storages for procured materials	10.992	238	.000	3.286	3.384	3.973
Infromation flows	6.512	238	.000	3.352	3.210	3.380

Source: Authors Survey (2023

5. CONCLUSION

This study examined the impact of logistics factors on the procurement of building construction materials in Lokoja, Kogi State. Eight key factors were identified: on-time delivery, transportation challenges, incorrect delivery locations, delivery inaccuracies, order processing, adequate storage, and information flows. Hypothesis testing revealed a statistically significant relationship between these factors and material procurement efficiency, aligning with previous studies by Abdullateef et al. (2022), Tarun et al. (2016), Tunji-Olayeni et al. (2017), and Kiromo (2015), which similarly highlighted transportation issues, delays, and delivery inaccuracies as significant procurement challenges.

In conclusion, addressing these logistics factors is critical to minimizing cost overruns, reducing waste, and ensuring timely project delivery. To achieve this, project managers should implement a centralized procurement system supported by project management software with real-time tracking, which can streamline processes and reduce delays. Vendors must be provided with accurate delivery instructions using digital maps and GPS, with a system for confirming delivery locations through mobile platforms to avoid errors. Contractors with adequate financial resources should consider owning or leasing transportation vehicles to reduce dependency on third-party logistics providers; this should be complemented by staff training on vehicle operations and management. Furthermore, establishing effective communication channels through tools such as video conferencing, instant messaging, and shared platforms can minimize miscommunication and ensure accurate order processing. Finally, construction companies should invest in temporary storage solutions near project sites, such as weather-resistant and secure units, to protect materials from environmental damage and theft while ensuring easier accessibility during construction activities. By addressing these logistics challenges through targeted strategies, construction firms can significantly improve procurement efficiency, reduce project delays, and achieve successful project outcomes.

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ANALYTICAL STUDY ON THE INTENSITY OF SURFACE URBAN HEAT ISLAND (SUHI) IN KADUNA STATE

Paul Onibaba[1*], Kolade Victor Otokiti[2], Oluwabukola Grace Ademola[1], and Temitope Akanle[3]

[1]*Departmenet of Urban and Regional Planning, University of Ibadan, Nigeria*
[2]*Faculty of Spatial Sciences, University of Groningen, the Netherlands*
[3]*Redeemer's University, Ede, Osun, Nigeria*

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ABSTRACT

Urbanization and climate change are significant drivers of rising Land Surface Temperature (LST) and the formation of Urban Heat Islands (UHIs), which have emerged as pressing environmental challenges in recent decades. This study examines the relationship between Land Use/Cover (LU/C) indices and LST in Kaduna, Nigeria, using multi-temporal Landsat imagery spanning five periods from 2001 to 2021. LST values were derived from the Landsat thermal bands, while LU/C dynamics were identified using the Maximum Likelihood Classifier algorithm. LU/C indices—including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI), Modified Normalized Difference Water Index (MNDWI), and Soil-Adjusted Vegetation Index (SAVI)—were generated to evaluate their correlation with LST. The results highlight a substantial increase in built-up areas over the 20-year period, accompanied by rising LST values, particularly over bare land and built-up regions, while water bodies exhibited the lowest LST values. Among the LU/C indices, NDBI showed the strongest positive correlation with LST, emphasizing the influence of urban expansion on surface thermal dynamics. The study underscores the critical need for sustainable urban planning and holistic design strategies to mitigate rising LST and SUHI effects in rapidly urbanizing regions like Kaduna.

Keywords: Land surface temperature; Land use/cover; Kaduna; Landsat

1. INTRODUCTION

Globally, the rapid pace of urbanization and soaring population growth are defining trends in 21st-century cities, with significant implications for environmental systems (Cai et al., 2016). Currently, urban areas accommodate approximately 54% of the world's population, a figure projected to approach 70% by 2030, with Africa playing a central role in this demographic shift (Son et al., 2017; UNDESA, 2018). Among the fastest-growing urban regions globally, Nigeria is expected to contribute alongside China and India to approximately 35% of the global population increase by 2050 (United Nations, 2018). However, this rapid urban growth comes with substantial environmental challenges, particularly the phenomenon of Surface Urban Heat Island (SUHI), a critical issue exacerbated by urban expansion (Du et al., 2016). Since the late 19th century, the world has witnessed a steady increase in surface temperatures, highlighting the urgent need for targeted intervention (Hansen et al., 2006).

*Corresponding author's email: paulonibaba@gmail.com
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The SUHI effect describes elevated urban temperatures compared to adjacent rural regions, particularly in densely populated areas with minimal vegetation cover (Lauriola, 2016; Voogt and Oke, 2003; Gartland, 2008). Its impacts are far-reaching, including altered vegetation cycles (Zipper et al., 2016), reduced air quality, increased energy consumption (Stafoggia et al., 2008), and greater risks of heat-related health issues, such as aggravated respiratory conditions and elevated mortality among vulnerable populations (Rocklov et al., 2014; Kjellstrom and Holmer, 2009). Additional consequences include fire hazards (T E R I, 2017), diminished workforce productivity (Kjellstrom et al., 2016), and forced migration in extreme cases (Lulla et al., 2015). These cumulative effects position SUHI as a pressing environmental issue requiring interdisciplinary solutions that span urban planning, public health, and climatology (Semudara et al., 2024; Jimoh and Otokiti, 2022).

The transformation of natural environments—such as vegetation, water bodies, and wetlands—into urban landscapes contributes significantly to changes in Land Use/Cover (LU/C) patterns, which in turn influence urban thermal dynamics (Foley et al., 2005; Gogoi et al., 2019). Understanding these dynamics through the analysis of LU/C variations across spatial and temporal scales has proven critical for identifying environmental impacts and developing targeted mitigation strategies (Firozjaei et al., 2018; Lai, 2020; Guyassa et al., 2018; Fenta et al., 2017; Semudara et al., 2024).

To study the relationship between LU/C and Land Surface Temperature (LST), integrating Geographic Information System (GIS) tools with remotely sensed data has become a widely adopted approach (Jimoh and Otokiti, 2022; Choudhury et al., 2019). Landsat satellite imagery remains the predominant dataset in SUHI research, accounting for nearly 89% of applications globally (Deilami et al., 2018). This study leverages multi-temporal Landsat data (2001–2021) to evaluate LU/C indices—NDVI, NDBI, MNWVI, and SAVI—and their correlations with LST. The findings aim to provide evidence-based insights for sustainable urban planning and SUHI mitigation in Kaduna, Nigeria.

2. LITERATURE REVIEW

The phenomenon of the Surface Urban Heat Island (SUHI) was initially identified and described by Howard in 1815 during his study in London. Using thermometers strategically placed in both urban and rural areas, Howard systematically recorded temperature variations, revealing a noticeable difference between the two environments (Ashley, 2016). SUHI has since been widely recognized as a consequence of urbanization and industrialization, leading to elevated temperatures in urban areas compared to surrounding suburban and rural regions (Vailshery, 2013; Czarnecka and Nidzgorska-Lencewicz, 2014; He, 2018; Ulpiani, 2021; Kaveh et al., 2016).

Nwilo et al. (2012) highlighted that LST progressively decreases as one moves outward from urban centers to peripheral areas. They further observed that temperature variations within urban areas are closely linked to land use and land cover patterns. Several factors contribute to the SUHI effect, including the decline of surface moisture, limited vegetation, urban geometry, industrial emissions, and the prevalence of surfaces that absorb rather than reflect heat (Ayanlade, 2016; He, 2018; Ulpiani, 2021). These factors not only exacerbate urban temperatures but also lead to environmental degradation and pose serious health risks, such as heat-related illnesses and mortality (Archisman, 2017).

Globally, numerous studies have demonstrated a positive association between urbanization and the intensity of the SUHI effect (Kaya et al., 2012; Dihkan et al., 2018; Das, 2022). For example, Ukaegbu et al. (2016) found that increased development activities in Owerri significantly altered land cover patterns, resulting in elevated urban temperatures. Similarly, Mande and Abishaya

(2020) reported that urban expansion in Kaduna, Nigeria between 2000 and 2018 contributed to a warmer and drier urban climate. In Abuja, Isioye et al. (2020) identified LST variations ranging from 19°C to 39°C, with cooler conditions predominantly recorded in less developed, peripheral areas. Furthermore, Abbas et al. (2021) observed a steady rise in LST in Kubwa, Abuja, from 1990 to 2020, with a notable increase of 2°C during the decade spanning 2010–2020. This trend was directly attributed to urban growth and anthropogenic influences.

Despite extensive global research on SUHI and its relationship with land use/cover (LU/C) changes, there remains a critical knowledge gap concerning the city of Kaduna, Nigeria. While SUHI effects have been studied in many contexts, localized investigations focusing on the interaction between LU/C indices and LST in Kaduna are limited. This study seeks to address this gap by offering region-specific insights into SUHI dynamics, emphasizing actionable strategies for urban planning and sustainable development.

3. MATERIAL AND METHOD

3.1. Study Area

Kaduna is located in Nigeria's northern Guinea Savannah zone and spans approximately 130.66 square kilometers. Geographically, it lies between latitudes 10°22'30" N and 10°33'0" N and longitudes 7°25'0" E and 7°30'0" E (Figure 1). The city's climate is predominantly shaped by two weather systems: the Sahara high-pressure system and the Atlantic low-pressure system. A key physical feature of Kaduna is the River Kaduna, which divides the city into two unequal parts.

Historically, the natural vegetation in Kaduna consisted of dense woodlands and tall grasses, with trees reaching heights of 8–15 meters. Over time, however, urbanization, grazing, intensive agriculture, and frequent burning have significantly modified this landscape (Obasanjo, 2015). These human activities have exacerbated the Urban Heat Island (UHI) effect in the city, disrupting its natural cooling mechanisms.

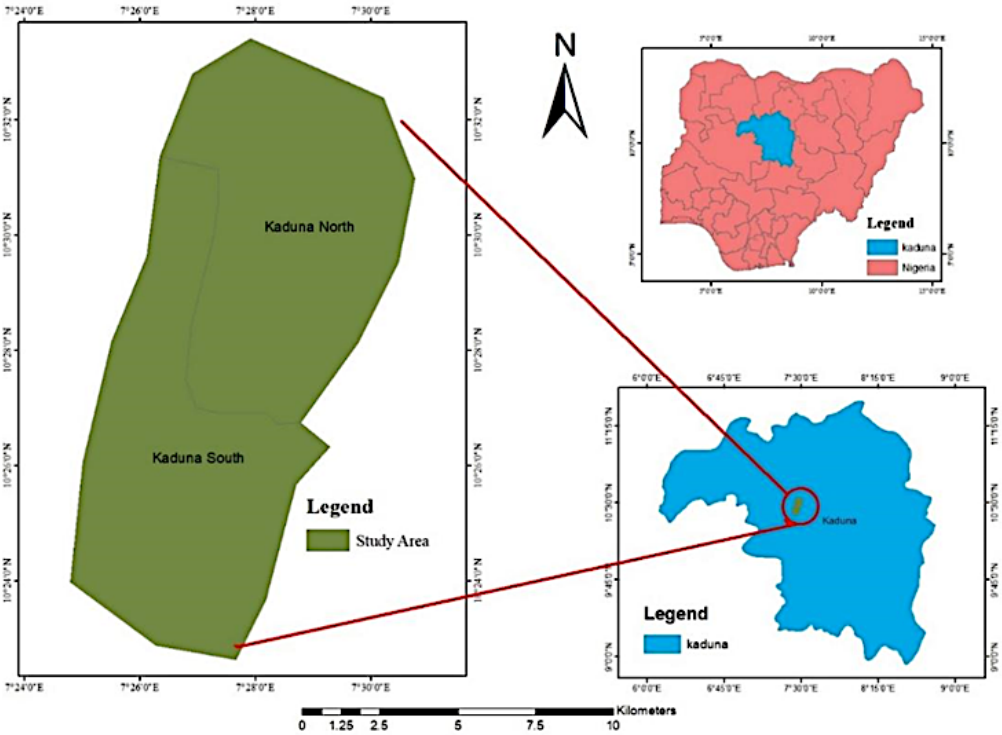

Figure 1 Study Area Map

3.2. Methods

This study employed a combination of geoprocessing techniques to assess changes in Land Use/Cover (LU/C) and their relationship with LST. The primary steps in the image processing included LU/C classification, the derivation of LU/C indices, and LST computation (see Figure 2).

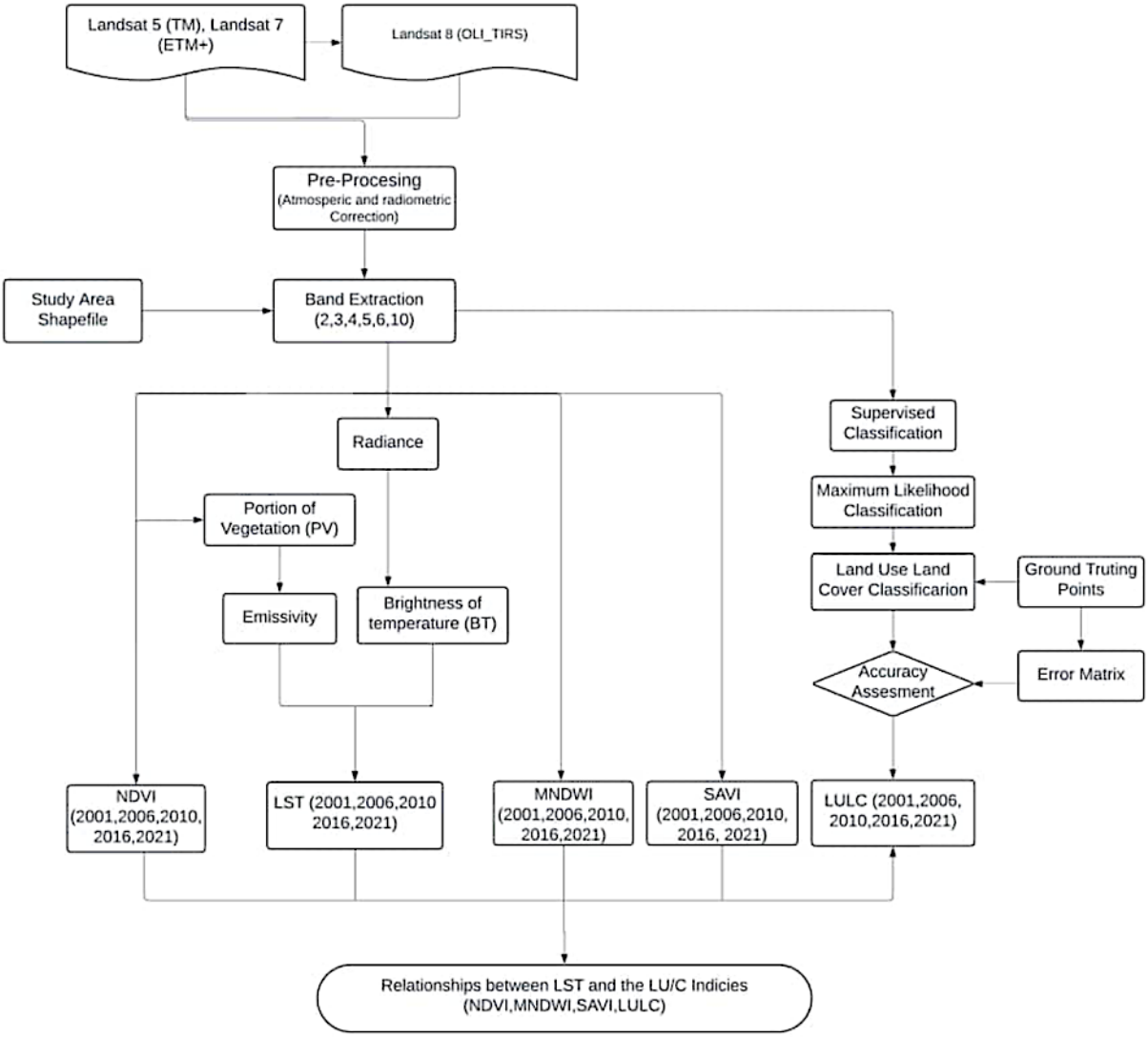

Figure 2 Image Processing Flowchart

3.2.1 LU/C Configuration

Multi-temporal Landsat imagery for the years 2001, 2006, 2010, 2016, and 2021 was obtained from the United States Geological Survey (USGS) archive (Table 1). The study utilized the Maximum Likelihood Classifier (MLC) algorithm, a supervised classification technique that identifies spectral signatures by comparing Landsat images with Google Earth reference data for the corresponding years (Ahmed & Quegan, 2012).

Kaduna was categorized into four distinct LU/C classes: built-up areas, water bodies, vegetation, and bare land. These classifications remained consistent throughout the study period, enabling comparative analysis across the selected years.

Table 1 Data Used and Source

S/N	Data	Sensor	Band	Resolution	Source	Ref. System
1	Landsat-5	Thematic Mapper ™	2-5	30m	USGS	WGS 1984
			6	120m	Archive	
2	Landsat-7		2-5	30m	USGS	WGS 1984
			6L	120m	Archive	
			6H	120m		
3	Landsat-8	Operational Land Imager (OLI)	3-6	30m	USGS	WGS 1984
		Thermal Infrared Sensor (TIR)	10 & 11	100m	Archive	

To validate the LU/C classification results, 20 reference points were randomly selected for each LU/C class and compared against ground reference images. The Kappa coefficient and overall classification accuracy were calculated following Sultana and Satyanarayana (2018). The results indicated that the overall classification accuracy ranged from 89.09% to 91.25%, with Kappa coefficient values consistently above 0.85 (Table 2). These values exceed the 80% minimum accuracy threshold recommended by Anderson (1976), confirming the reliability of the LU/C maps generated for this study.

Table 2 Overall Classification Accuracy and Kappa Statistics for Accuracy Assessment

Years	Overall-Classification Accuracy (%)	Overall-Kappa Statistics
2001	91.25	0.88
2006	89.09	0.85
2010	89.25	0.86
2016	91.25	0.88
2021	91.25	0.88

3.2.2 Derivation of LU/C Indices

The study utilized LU/C indices to analyze relationships between land biophysical features and LST. The indices applied were:

Normalized Difference Vegetation Index (NDVI) that assesses vegetation density (Townshend and Justice, 1986).

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

Modified Normalized Difference Water Index (MNDWI) that evaluates water body configuration according to Xu (2006).

$$MNDWI = \frac{G - MIR}{G + MIR} \tag{2}$$

Normalized Difference Built-up Index (NDBI) that detects built-up configuration (Zha et al., 2003).

$$NDBI = \frac{SWIR1 - NIR}{SWIR1 + NIR} \tag{3}$$

Soil-Adjusted Vegetation Index (SAVI), that adjusts for soil brightness for vegetation configuration (Huete,1988).

$$SAVI = \frac{(NIR - R)(1 + l)}{(NIR + R + l)} \quad (4)$$

Note: NIR represents the Near Infrared Band, R is the Red Band, G is the Green Band, MIR is the Middle Infrared Band, SWIR1 refers to Shortwave Infrared Band, and L is the adjustment factor.

3.2.3 Estimation of LST from Landsat Images

The study applied the mono-window algorithm (Qin et al., 2001) to estimate LST, following three key steps:

1. Spectral Radiance Extraction
   Spectral radiance is extracted from the digital number (DN) of the Landsat images using the following formula:

$$L(\lambda) = \frac{LMAX - LMIN}{255} * DN + LMIN \quad (5)$$

   Where, $L(\lambda)$ w $sr^{-1}m^{-3}$. $LMIN$ is spectral radiance of DN value 1 and $LMAX$ is spectral radiance of DB value 255. DB is Digital number.

Is spectral radiance Trasnformation to Temperature (Kelvin)

2. Conversion to Temperature (Kelvin)
   Radiance is converted to temperature in Kelvin using the following formula:

$$TB = \frac{K2}{In\frac{K1}{R} + 1} \quad (6)$$

   Where. TB is LST (kelvin), $K1$ is calibration sonstant 1. $K2$ is Calibration constant 2 and R is radiance values.

3. Conversion to Celcius
   Finally, temperature in Kelvin is converted to celcius:

$$Tc = TB - 273 \quad (7)$$

   Where, Tc is LST in celcius.

3.2.4 Data Analysis

The relationship between LST and LU/C classes was analyzed by extracting temperature values for each land cover type. Minimum, maximum, and mean LST values were calculated using the Band Collection Statistics tool in ArcMap. Finally, regression analysis was employed to examine how LU/C indices (NDVI, NDBI, SAVI, MNDWI) influenced LST across the study years (2001–2021).

4. RESULTS AND DISCUSSION

4.1. LU/C Configuration over the Study Period

The statistical distribution of LU/C classes in Kaduna, as presented in Table 3 and illustrated by the thematic map in Figure 3, provides a detailed perspective on the transformations that occurred in the study area over the period under consideration. One of the most prominent observations is the significant increase in built-up areas, which reflects the rapid urbanization experienced in Kaduna. Between 2001 and 2021, the built-up area expanded from 12.67 km² to 34.44 km², a change that corresponds with the increasing demand for housing, infrastructure, and other urban developments. However, this growth has come at the expense of natural resources, particularly vegetation and water bodies. Vegetation cover declined drastically from 38.92 km² to 17.72 km², while the water bodies shrank from 1.58 km² to 0.60 km². Such changes highlight the pressure exerted on natural ecosystems, which are critical for maintaining the thermal balance in urban areas.

These transformations are particularly concerning because vegetation and water bodies play a fundamental role in mitigating urban heat by providing shade and promoting evaporative cooling. As natural cooling mechanisms, their reduction has been recognized as a key contributor to the intensification of the Surface Urban Heat Island (SUHI) effect, a phenomenon that amplifies urban temperatures (Semudara et al., 2024). Fu and Weng (2018) emphasize the importance of these natural elements in regulating urban climates; however, their disruption due to rapid urban expansion exacerbates thermal stress in cities. The LU/C changes observed in Kaduna underscore the need for sustainable urban development strategies to balance growth and environmental preservation.

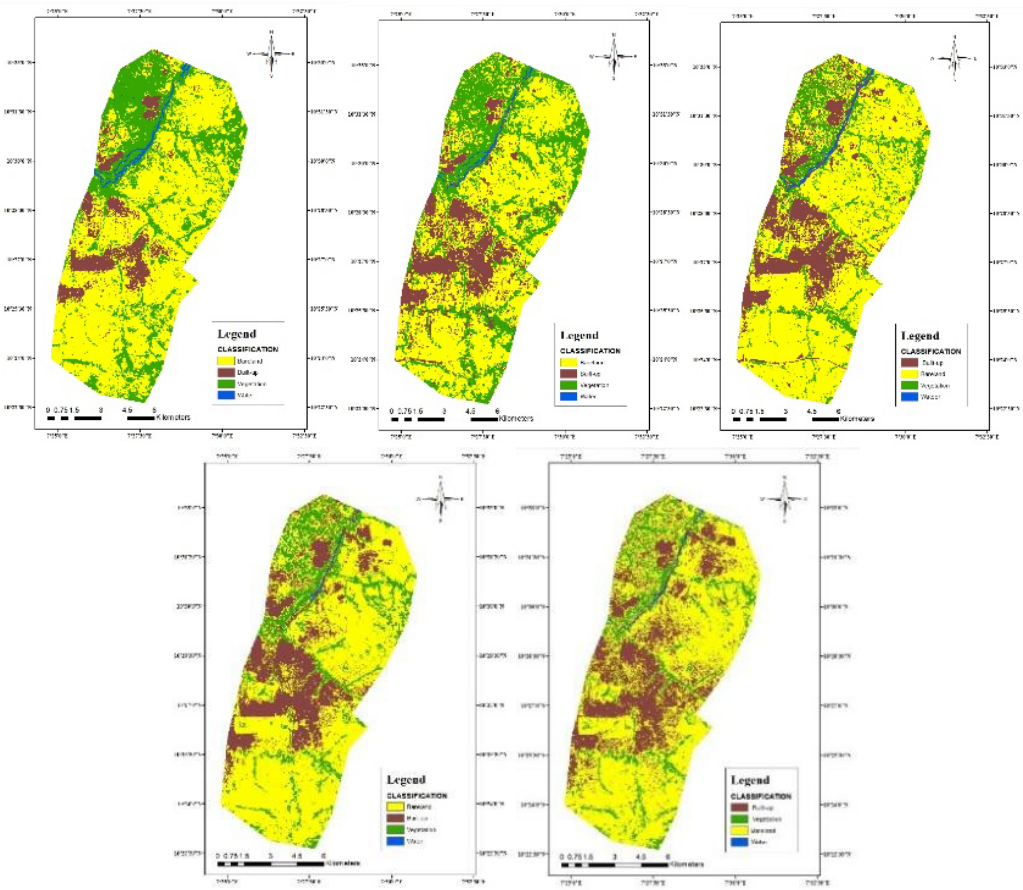

Figure 3 LU/C Configuration

Table 3 Statistical Distribution of the LU/C Classes and Change over the Study Period

Ima	LU/C Configuration			
	Built-up (SqKm)	Water (SqKm)	Vegetation (SqKm)	Bare Land (SqKm)
2001	12.67	1.58	38.92	77.49
2006	22.85	0.94	39.12	67.75
2010	25.06	1.00	22.36	82.24
2016	29.99	0.38	22.49	77.80
2021	34.44	0.60	17.72	77.90
Change 2021 - 2001	21.77	-0.98	-2.12	0.41

4.2. Spatio-temporal Distribution of LST over Kaduna

The spatio-temporal distribution of LST across Kaduna reveals notable patterns over the study period, with Figure 4 illustrating the spatial variations in LST across the city. The analysis indicates that areas with high LST values are predominantly concentrated in the southern part of the city, which corresponds with the regions experiencing significant urban expansion and reductions in vegetation cover. Conversely, regions with low LST values are primarily located in the northern part, where natural vegetation and open spaces remain relatively intact. Over the study period, the mean LST exhibited substantial fluctuations, rising from 27.85°C in 2001 to a peak of 31.39°C in 2010. Interestingly, a sharp decline occurred in 2016, where the mean LST dropped to 24.42°C, before rising again to 30.18°C in 2021 (Table 4).

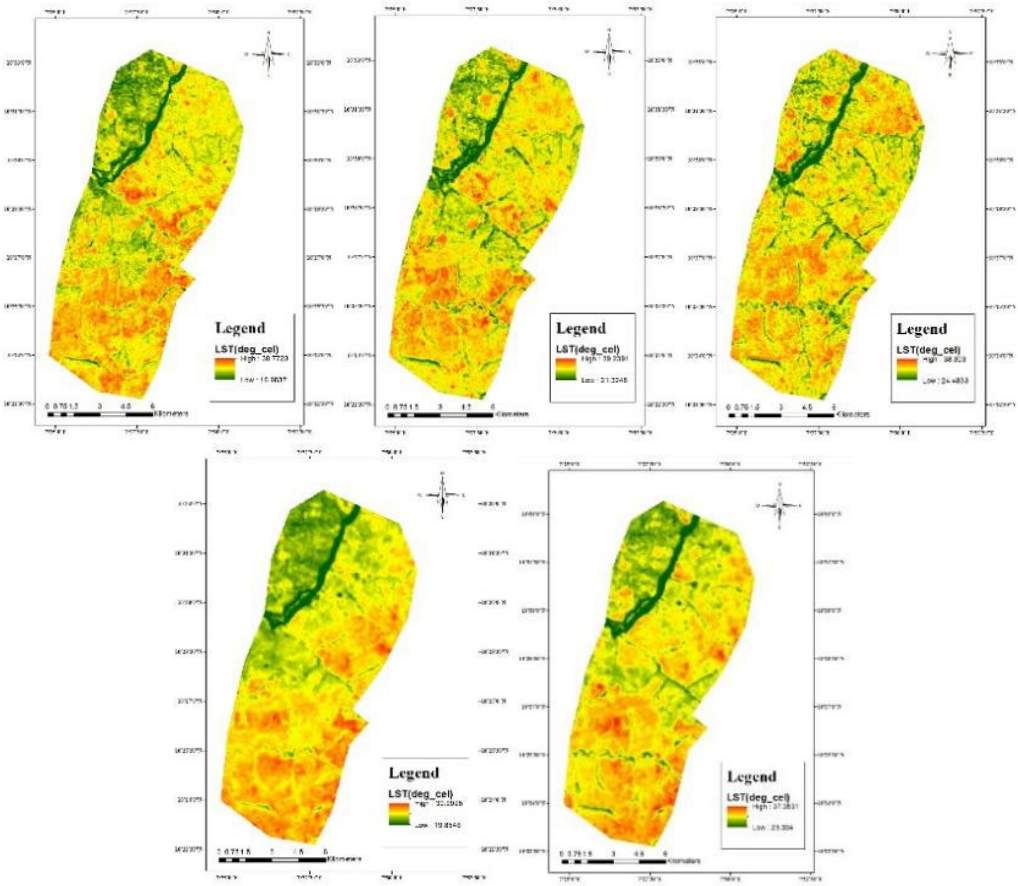

Figure 4 Changes in LST

The observed trends suggest that the intensity of the SUHI effect in Kaduna was at its weakest in 2016 and at its strongest in 2010. These variations can be attributed to changes in LU/C patterns, which directly influence the city's thermal dynamics. For instance, the reduction in vegetation and expansion of built-up areas likely contributed to the temperature peak observed in 2010, while any temporary increase in vegetation or other mitigating factors may explain the lower LST recorded in 2016. The results highlight the strong link between urban development patterns and SUHI intensity, reaffirming the importance of integrating LU/C planning with temperature mitigation strategies in urban areas.

Table 4 Changing Patterns of LST

Years	Min. Temp. (°C)	Max. Temp. (°C)	Mean Temp. (°C)
2001	16.98	38.77	27.85
2006	21.32	39.24	30.28
2010	24.48	38.30	31.39
2016	19.85	30.99	24.42
2021	23.00	37.35	30.18

4.3 Variation of LST over Different LU/C Classes

The analysis of LST across different LU/C classes over the study period reveals consistent patterns that underscore the thermal dynamics of Kaduna's urban landscape. Built-up areas and bare land consistently recorded the highest temperatures, while vegetation and water bodies exhibited lower LST values due to their natural cooling properties (see Table 5). In 2010, for example, bare land recorded the highest temperature at 33.92°C, whereas the lowest temperature, 21.82°C, was observed over water bodies in 2016. These findings align with the thermal characteristics of these LU/C classes, as bare surfaces and built-up areas tend to absorb and radiate more heat compared to vegetation and water.

A detailed comparison between built-up areas and other LU/C classes further highlights the growing influence of urbanization on temperature increases. In 2001, the mean LST for built-up areas was 0.15°C higher than vegetation and 4.26°C higher than water. By 2006, the difference between built-up areas and vegetation had expanded to 0.85°C, while the gap with water increased to 5.57°C. This trend continued in 2010, where the LST gap between built-up areas and vegetation reached 1.2°C, and the difference with water peaked at 7.03°C. A slight decline in these margins occurred in 2016, with built-up areas being 0.52°C warmer than vegetation and 4.88°C warmer than water. However, by 2021, the mean LST difference had risen again to 0.31°C for vegetation and 6.33°C for water.

Table 5 LST Variation over Different LU/C Classes

Years	LST (deg.cel)	Average LST (deg.cel)
2021		
Buildt-up	25.45 - 32.96	27.47
Bareland	21.33 - 34.44	29.16
Vegetation	20.53 - 32.04	27.32
Water	16.98 - 25.99	23.21
2006		
Buildt-up	21.86 - 33.48	29.16
Bareland	22.39 - 33.02	29.77
Vegetation	21.86 - 30.53	28.31
Water	21.32 - 26.54	23.59
2010		

Years	LST (deg.cel)	Average LST (deg.cel)
Buildt-up	25.00 - 36.84	33.81
Bareland	25.00 - 36.37	33.92
Vegetation	25.52 - 34.94	32.61
Water	24.48 - 29.53	26.78
2016		
Buildt-up	20.34 - 30.30	26.70
Bareland	20.23 - 30.99	27.35
Vegetation	20.48 - 28.73	26.18
Water	19.86 - 24.07	21.82
2021		
Buildt-up	23.05 - 37.20	31.90
Bareland	28.33 - 37.35	32.90
Vegetation	23.08 - 33.62	31.59
Water	23.00 - 28.04	25.57

These findings confirm that built-up areas act as critical amplifiers of the SUHI effect, as highlighted by Rizvi et al. (2020), while vegetation and water bodies continue to serve as essential cooling agents. The consistent thermal disparities between LU/C classes further emphasize the need to preserve and expand vegetation and water resources within urban environments to mitigate the adverse effects of urban heat.

4.4. Impact of LU/C Indices on LST

The impact of LU/C indices on LST was assessed through Pearson's Product-Moment Correlation, which revealed distinct patterns over the study period. Figures 5 to 8 illustrate the variations in the selected LU/C indices, including NDVI, SAVI, MNDWI, and NDBI, and their relationship with LST. In 2001 and 2006, LST exhibited a **negative correlation** with NDVI, SAVI, and MNDWI, indicating that vegetation and water bodies played a cooling role during these periods. Conversely, LST demonstrated a **positive correlation** with NDBI, emphasizing the contribution of built-up areas to temperature increases.

By 2010 and 2016, the relationships shifted slightly, as LST showed a positive correlation with NDVI and SAVI, while MNDWI maintained a negative correlation. These findings suggest that changes in vegetation cover and water resources influenced urban thermal dynamics during these years. In 2021, the results indicated a strong positive correlation between LST and NDBI, while NDVI, SAVI, and MNDWI maintained negative correlations. Notably, NDBI consistently exhibited the strongest correlation with LST across all years, underscoring its critical role in urban heat dynamics and highlighting the direct impact of built-up areas on LST.

Table 6 summarizes the correlation coefficients, providing a quantitative perspective on the relationships between LST and LU/C indices. The findings reinforce the need for urban planning policies that focus on reducing the expansion of built-up areas while promoting vegetation and water conservation to mitigate the SUHI effect.

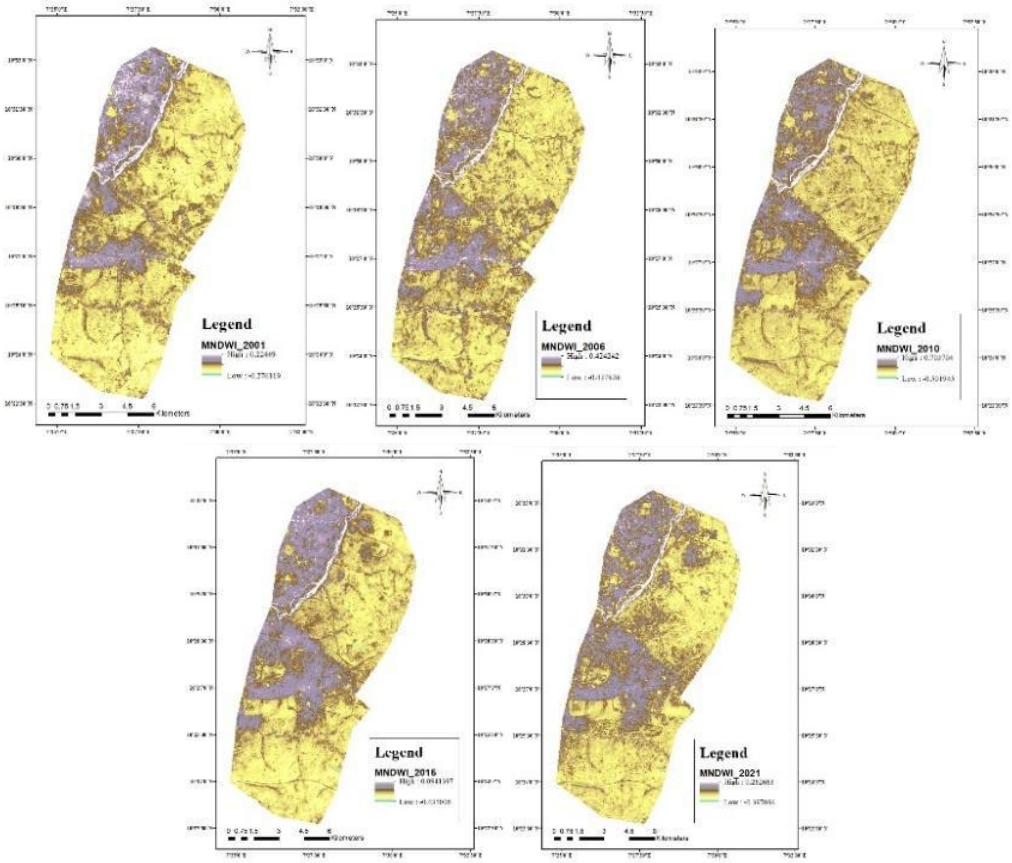

Figure 5 Changes in MNDWI

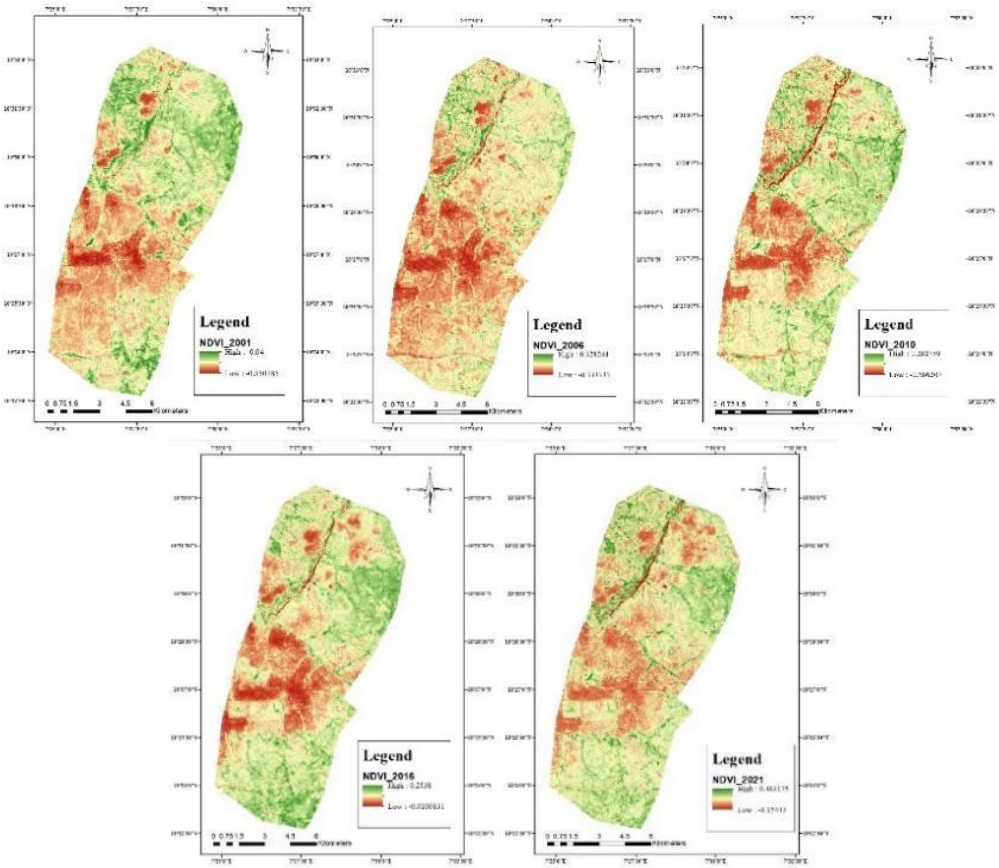

Figure 6 Changes in NDVI

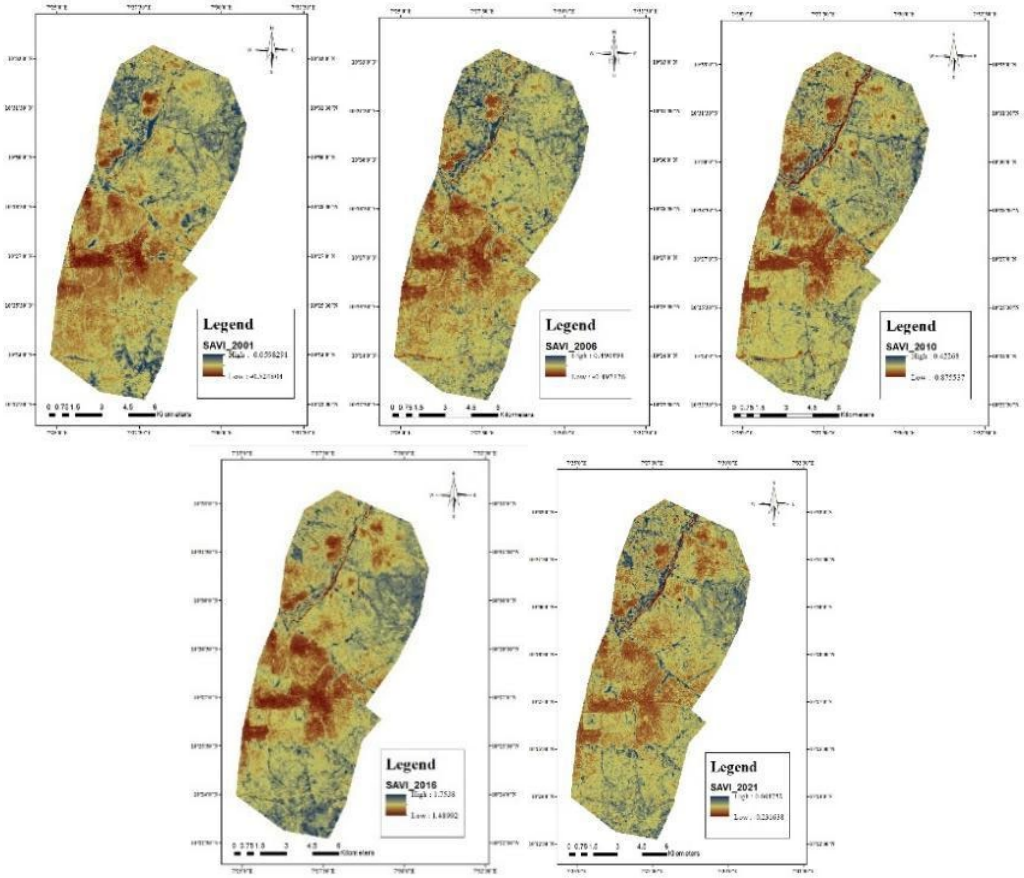

Figure 7 Changes in SAVI

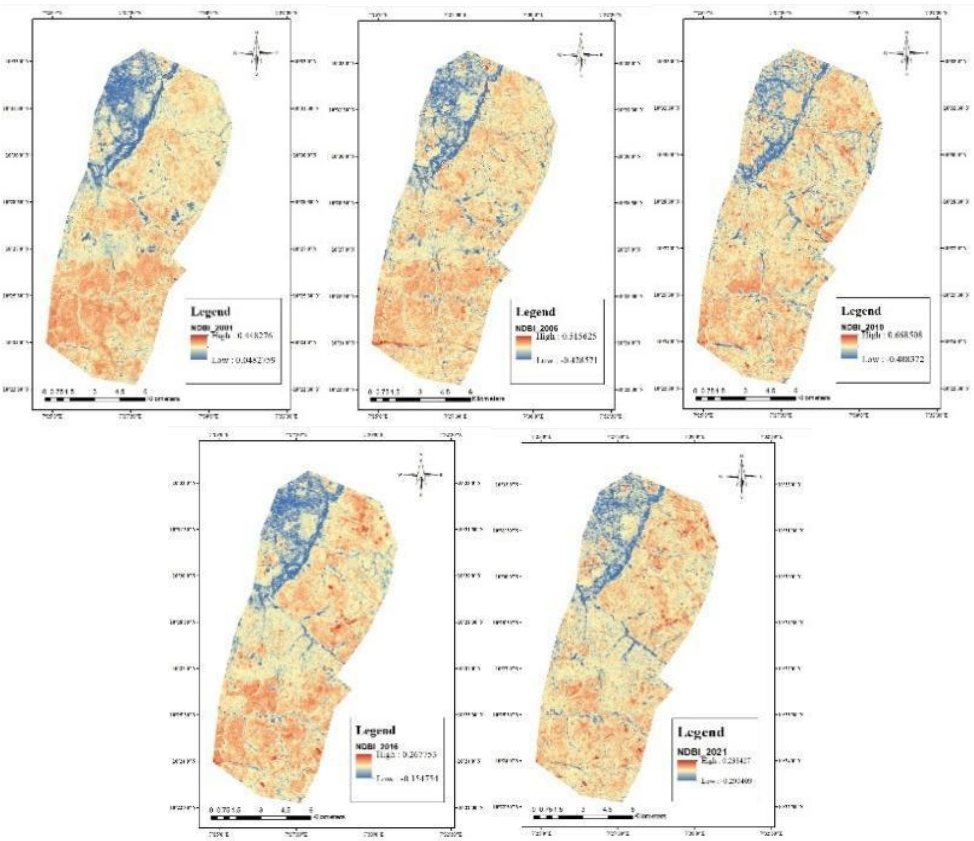

Figure 8 Changes in NDBI

Table 6 Correlation Coefficient Values of LST with Different LU/C Indices

2001					
Layer	**LST**	**NDVI**	**SAVI**	**MNDWI**	**NDBI**
LST	1.00	-0.25	-0.25	-0.52	0.58
NDVI	-0.25	1.00	1.00	-0.07	-0.50
SAVI	-0.25	1.00	1.00	-0.07	-0.51
MNDWI	-0.52	-0.07	-0.07	1.00	-0.79
NDBI	0.58	-0.50	-0.51	-0.79	1.00
2006					
Layer	**LST**	**NDVI**	**SAVI**	**MNDWI**	**NDBI**
LST	1.00	-0.25	-0.25	-0.46	0.52
NDVI	-0.25	1.00	1.00	-0.13	-0.51
SAVI	-0.25	1.00	1.00	-0.13	-0.51
MNDWI	-0.46	-0.13	-0.13	1.00	-0.75
NDBI	0.52	-0.51	-0.51	-0.75	1.00
2010					
Layer	**LST**	**NDVI**	**SAVI**	**MNDWI**	**NDBI**
LST	1.00	0.03	0.03	-0.54	0.49
NDVI	0.03	1.00	1.00	-0.43	0.41
SAVI	0.03	1.00	1.00	-0.43	-0.41
MNDWI	-0.54	-0.43	-0.43	1.00	-0.62
NDBI	0.49	-0.41	-0.41	-0.62	1.00
2016					
Layer	**Layer**	**Layer**	**Layer**	**Layer**	**Layer**
LST	1.00	0.01	0.01	-0.55	0.59
NDVI	0.01	1.00	1.00	-0.49	-0.25
SAVI	0.01	1.00	1.00	-0.49	-0.25
MNDWI	-0.55	-0.49	-0.49	1.00	-0.70
NDBI	0.59	-0.25	-0.25	-0.70	1.00
2021					
Layer	**LST**	**NDVI**	**SAVI**	**MNDWI**	**NDBI**
LST	1.00	-0.05	-0.05	-0.05	0.59
NDVI	-0.05	1.00	1.00	-0.46	-0.38
SAVI	-0.05	1.00	1.00	-0.46	-0.38
MNDWI	-0.56	-0.46	-0.46	1.00	-0.62
NDBI	0.59	-0.38	-0.38	-0.62	1.00

5. MITIGATING SUHI TROUGH SUSTAINABLE URBAN PLANNING AND DESIGN

The observed trends of urbanization in Kaduna from 2001 to 2021 are particularly concerning, with built-up areas increasing from 12.67 km² to 34.44 km², while vegetation and water bodies experienced substantial declines from 38.92 km² to 17.72 km² and from 1.58 km² to 0.60 km², respectively. These findings demonstrate the significant impact of land cover transformations on SUHI intensity, with vegetation loss and the proliferation of impermeable surfaces exacerbating urban thermal stress. The results of this study align closely with earlier research (Meenal and Rajashree, 2017; Mande and Abashiya, 2020; Yusuf et al., 2023), which similarly established strong correlations between rapid urbanization and the intensification of SUHI.

The critical role of water bodies and vegetation in alleviating SUHI effects is well-documented in existing literature. For instance, Robitu et al. (2006) observed that expanding water bodies can lower urban temperatures by enhancing evaporative cooling processes and promoting airflow. Similarly, Völker et al. (2013) emphasized the cooling potential of "urban blue" infrastructure, such as lakes, rivers, and ponds, due to their capacity to regulate land surface temperatures. These natural elements play a crucial role in mitigating SUHI intensity by fostering microclimates conducive to heat reduction.

To effectively combat SUHI effects, urban planners and city managers must adopt sustainable strategies that prioritize environmentally responsive urban designs. Replacing impervious surfaces, which restrict water infiltration, with pervious pavements has been shown to moderately reduce land surface temperature (Sailor, 2006; Adeyeri et al., 2017). In addition, implementing cool roofs and green roofs offers proven methods for lowering SUHI intensity and improving urban thermal comfort, as highlighted by O'Malley et al. (2015) and Zhang et al. (2017). These approaches reduce the absorption of solar radiation and promote natural cooling processes, making urban areas more livable and energy-efficient.

Strategic urban design plays a pivotal role in addressing SUHI by incorporating innovative planning solutions. Yamamoto (2006) proposed the development of riverbanks with winding pathways and riverfront structures that facilitate the movement of cooler air throughout urban spaces. Similarly, Tanko et al. (2017) advocated for urban redesigns that integrate parks, gardens, orchards, and other green spaces to enhance air circulation, provide shade, and reduce surface temperatures. In line with these strategies, Ojeh et al. (2016) recommended climate-smart urban planning, where decentralized economic activities are situated away from congested urban cores to minimize heat accumulation. Ningrum (2018) further emphasized the importance of spatial development planning that incorporates expansive green open spaces, which serve as natural buffers against rising temperatures in urbanized areas.

Given the escalating SUHI effects resulting from Kaduna's rapid urban expansion, it is imperative to implement urgent, sustainable interventions. A balanced integration of green infrastructure (vegetation, parks, gardens) and blue infrastructure (rivers, lakes, ponds) can help mitigate urban heat, restore environmental equilibrium, and enhance urban resilience. These sustainable urban planning strategies not only address the adverse thermal impacts of SUHI but also contribute to the creation of healthier, more livable urban environments capable of withstanding climate-related challenges.

6. CONCLUSION

This study utilized multitemporal Landsat images spanning five time periods (2001, 2006, 2010, 2016, and 2021) to analyze the spatiotemporal dynamics of LU/C and LST in Kaduna, Nigeria. The findings revealed a significant expansion in built-up areas over the 20-year period, accompanied by rising LST values across all land cover classes. Bare land and built-up areas

consistently recorded the highest LST values, while water bodies exhibited the lowest temperatures. Notably, the study identified NDBI as the LU/C index most strongly correlated with LST, highlighting its critical role in influencing urban thermal dynamics and emphasizing the direct impacts of urbanization on surface temperatures.

The study underscores the urgent need for sustainable urban development strategies to mitigate the adverse effects of rapid urbanization on thermal environments. Implementing green infrastructure solutions, such as parks, community gardens, and urban forests featuring native vegetation, can significantly reduce LST in high-temperature areas while requiring minimal maintenance. Zoning regulations should mandate the integration of green spaces into new developments, and retrofitting existing urban layouts with vegetation can further enhance thermal regulation. Additionally, fostering community-led initiatives to develop and maintain green spaces will ensure local ownership and long-term sustainability. These findings provide a critical foundation for formulating targeted policies and interventions to mitigate SUHI effects in rapidly urbanizing regions like Kaduna and contribute to the broader understanding of urban environmental dynamics.

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ASSESSMENT OF PARKING FACILITIES IN PUBLIC AREAS: THE CASE OF KEFFI TOWN

Ayodeji Solomon Olatunji[1*], Enogela Ahmed John[1], Adeyemi Adewumi Adedeji[2], and Muhammed Loko Mikaila[3]

[1]*Department of Urban and Regional Planning, Federal University Oye-Ekiti, Nigeria*
[2]*Department of Urban and Regional Planning, Federal University of Technology, Minna, Nigeria*
[3]*Department of Urban and Regional Planning, Nasarawa State University, Keffi, Nigeria*

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ABSTRACT

The absence of adequate parking facilities in residential and public areas remains a significant issue in developing countries, often disrupting economic activities and environmental quality. In Keffi town, the increasing demand for parking exceeds the available supply, leading to congestion and inefficiency. This study evaluates the current public parking facilities, focusing on provision levels, infrastructure conditions, and management frameworks. Primary data were gathered using structured questionnaires and direct observations, with 328 valid responses analyzed through descriptive statistics. Results indicate that prolonged vehicle stays exacerbate congestion, such as at Nasarawa State University (32.8%) and Federal Medical Centre (29.1%). Parallel parking dominates (65.2%), and 91.6% of users rely on traditional search methods, highlighting the absence of modern parking guidance systems. The study recommends improving parking infrastructure with an emphasis on environmental standards, user convenience, safety, and the enforcement of effective regulatory frameworks.

Keywords: Assessment; Facilities; Parking; Public areas

1. INTRODUCTION

Urbanization and population growth in cities and towns have significantly increased vehicular traffic, posing challenges for the provision and management of parking infrastructure. Keffi Town, located in Nasarawa State, Nigeria, is a prime example of this trend. As a growing urban center with bustling commercial and social activities, the town experiences considerable daily vehicular movement, which has resulted in congestion, improper parking practices, and insufficient parking facilities (Arab & Umar, 2023; Agadagba & Ovye, 2024).

Parking has emerged as a critical issue in urban areas worldwide (Parmar et al., 2020). In Nigeria, increasing per capita income has led to a rise in automobile ownership, thereby escalating the demand for parking spaces, particularly in urban regions. While vehicle ownership improves travel efficiency and productivity, it also creates widespread challenges in managing limited urban space for both road traffic and parking. Balancing road usage and parking requirements remains costly and complex, with studies showing that vehicles are parked for over 80% of their lifecycle (RAC Foundation, 2004).

*Corresponding author's email: solomon.olatunji@fuoye.edu.ng
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High rates of vehicle ownership in Nigerian cities and suburbs have made parking spaces a contentious resource, especially in public areas. This increasing demand, coupled with urban traffic growth, has intensified parking-related challenges. Shoup's (2005) study of 11 international cities reveals that up to 30% of urban traffic stems from drivers searching for parking, with average search times of eight minutes. These challenges are particularly acute in Central Business Districts (CBDs) and other high-density public spaces. While CBDs thrive on their diverse and compact activity zones such as schools, markets, hospitals, shopping malls, and offices the growing number of private vehicles undermines these advantages, complicating traffic flow and diminishing urban efficiency (Adedeji, 2010; Nwachi et al., 2024; Olatunji et al., 2022).

Stationary vehicles also impose significant spatial demands in urban environments. A frequently used vehicle may occupy multiple parking spots throughout the day, with each parked car consuming up to 8 square meters of valuable land (Olatunji et al., 2020). In densely populated cities where land is costly, parking often disrupts traffic order and reduces the space available for other urban functions. This recurring demand for parking thus creates land-use conflicts, limits pedestrian accessibility, and adds financial burdens to urban infrastructure (Ma et al., 2014; Manjiri, 2016).

Parking accessibility is integral to urban mobility and destination connectivity. A vehicle must be parked before any activity can commence, making parking an essential component of trip planning. Ease of parking directly affects access to destinations and overall urban efficiency. Municipalities play a key role in defining and enforcing parking standards to prevent spillover onto adjacent streets and maintain smooth traffic flow (Wilson, 2000). The location and quantity of parking facilities influence traffic patterns, public space utilization, and urban environmental quality (Chukwuma et al., 2023; Ajala, 2019; Olatunji et al., 2021).

Well-managed parking facilities contribute to improved traffic flow, reduced congestion, and better access to urban spaces, ultimately enhancing residents' and visitors' quality of life (Dada et al., 2023). In contrast, inadequate or poorly managed parking systems lead to illegal parking, traffic bottlenecks, and restricted accessibility, detracting from urban functionality (Joel et al., 2022).

Keffi Town, situated as the gateway to Abuja the Federal Capital Territory (FCT) has experienced rapid urbanization due to an influx of residents seeking alternatives to Abuja's high living costs. The demolition of structures in Abuja in 2007 further accelerated Keffi's population growth, resulting in increased commercial activities, buildings, and vehicle ownership. Consequently, public spaces in Keffi face severe shortages of parking facilities, particularly in markets, hospitals, and educational institutions.

This study addresses the pressing parking challenges in Keffi Town by evaluating the current state of public parking facilities, including their provision, condition, and management practices. The study has two primary objectives: (1) to assess the extent of parking provision and evaluate the current condition of selected public parking facilities, and (2) to examine the management practices and regulatory frameworks governing parking facilities and propose sustainable measures to improve their effectiveness and efficiency

2. LITERATURE STUDY

2.1. Parking Characteristics

Parking spaces in public areas are essential components of transportation infrastructure, designed to accommodate vehicles requiring temporary stops. These spaces may be located on-street using existing road capacity or designated near buildings and facilities. Motorists often favor on-road parking because of its proximity to destinations and ease of access. However, insufficient parking capacity, particularly in densely populated residential areas, commercial hubs, and business

districts, can overload road space. This increased demand disrupts traffic flow and often results in infrastructure inefficiencies (Al Hawarneh et al., 2023; Bock et al., 2019).

Assessing parking characteristics is crucial for addressing parking challenges, as they serve as foundational criteria for designing efficient parking facilities. Parking capacity is determined by the types of vehicles accommodated, while parking accumulation refers to the number of vehicles parked at a given time. Parking turnover rate, another key metric, is calculated by dividing the total number of vehicles by the available spaces, offering insights into how frequently parking spots are utilized (Scheiner et al., 2020; Shaaban & Adalbi, 2021). In addition, the parking utilization rate and index are vital for measuring demand peaks and occupancy trends, which are indispensable for forecasting future parking requirements and planning effective infrastructure (Aritenang & Chandramidi, 2020).

To determine parking requirements, three main methodologies are employed. The first method calculates parking needs based on the floor area of a building, an approach commonly applied in retail and office complexes, where parking demand often correlates with building size. The second method evaluates the relationship between registered vehicles within a city's core and the available parking supply. Finally, the third approach identifies peak demand by measuring the difference between vehicle arrivals and departures, which is particularly important for determining the ideal capacity of parking facilities (Sweet & Ferguson, 2019). Parking accumulation, influenced by fluctuating urban activities, underscores the dynamic nature of parking demands in various urban spaces.

Urban environments often face difficulties in balancing parking supply with demand due to factors such as population density, land use, and economic activity patterns (Olatunji et al., 2020). High parking demand can result in illegal parking, prolonged search times, and overall traffic congestion. For instance, in Keffi, a fast-growing town in Nasarawa State, population growth, increased commercial activity, and the presence of institutions like Nasarawa State University have intensified vehicular traffic, particularly in commercial and public spaces. As demand outpaces the available supply, parking-related challenges in Keffi become increasingly acute.

2.2. Planning Standards

Planning standards represent legally established guidelines aimed at directing physical development within specific regions over defined time periods. These standards play a critical role in preventing urban decay and slum formation, highlighting the need for effective and timely implementation, particularly in light of current environmental and infrastructural challenges (Dada et al., 2023). Unfortunately, misapplication of land use regulations by public and government officials often leads to inappropriate construction near or over critical infrastructure, such as sewer lines, road reserves, wetlands, high-voltage power lines, and recreational or traffic safety areas. Changes in urban socio-economic priorities can further affect the adoption and enforcement of planning standards, impacting infrastructure design, demand management, and facility operations.

While planning standards provide essential frameworks for sustainable urban growth, they are often applied generically without sufficient consideration of local conditions. For example, cultural attitudes toward parking, enforcement mechanisms, and geographic constraints can vary significantly, particularly in emerging urban centers like Keffi. Unlike larger metropolitan areas, Keffi's unique characteristics including its urban layout, road networks, economic activities, and population density create distinct parking challenges that generalized findings may fail to address (Joel, 2022).

Relying on broad-scale data, such as national or regional averages for vehicle ownership, can further distort assessments of parking demand and supply in smaller towns like Keffi. Local factors, such as specific patterns of population growth and vehicle usage, often require tailored approaches to accurately reflect the town's parking needs. Therefore, localized planning standards that consider these unique urban dynamics are essential for mitigating parking challenges and ensuring sustainable infrastructure development.

3. METHOD

3.1. Study Area

Keffi is located in Northern Nigeria's basement complex, between longitude 7°49'03'' and latitude 8°46'05'' at an elevation of 400 meters above sea level. Established as a local government headquarters in 1976, Keffi has experienced rapid population growth and infrastructural development due to its proximity to Nigeria's Federal Capital Territory (FCT) of Abuja. The town is bordered by the Karu Local Government Area to the north, west, and south, and by the Kokona Local Government Area to the east (see Figure 1). As a critical access point to Abuja, Keffi's population grew from 124,900 in 2006 to a projected 196,093 by 2021, with a population density of 905.1 people per km² across its 138 km² area (NPC/NBS, 2016).

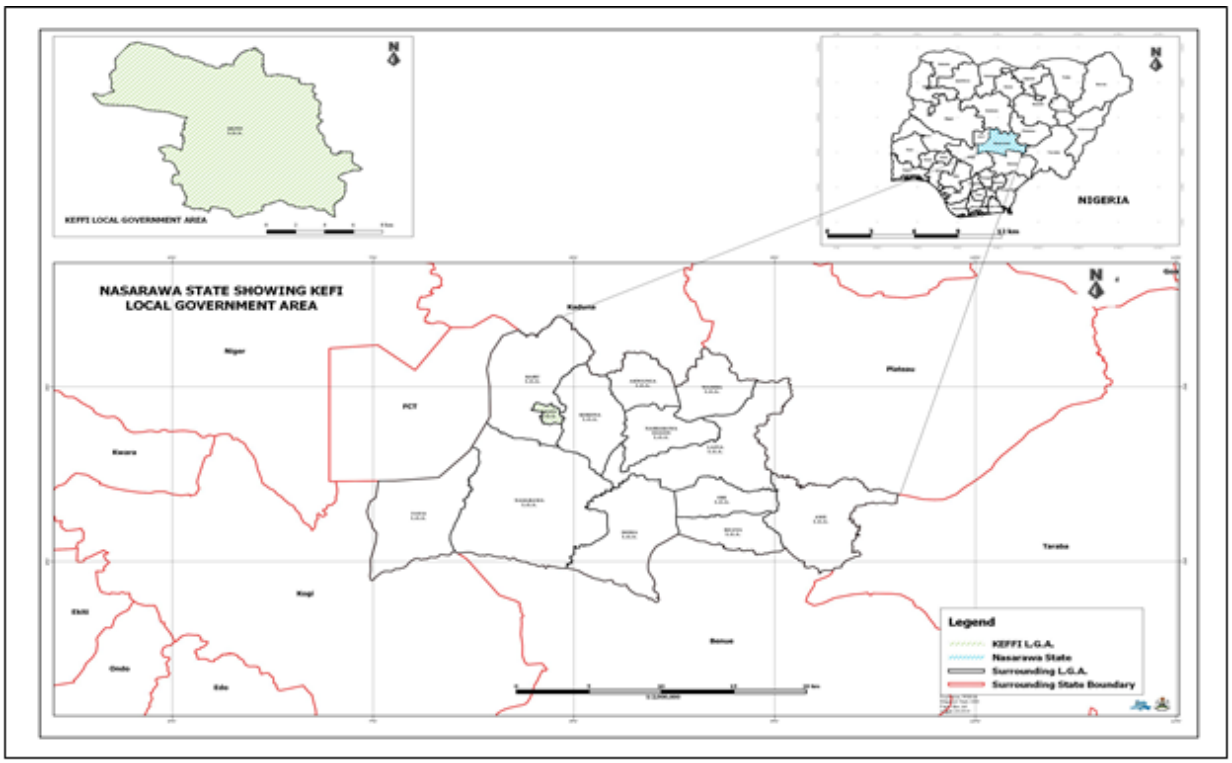

Figure 1 Map of Nigeria Nasarawa State and Nasarawa State Showing Keffi L.G.A
(source: Authors, 2022)

Figure 2 The Base Map of Keffi
(source: NAGIS, 2022)

3.2. Data Collection

To achieve the study's objectives, both primary and secondary data were collected. Primary data were obtained through structured questionnaires, respondent interviews, and physical observations. Research tools included open-ended and closed-ended questionnaires, visual documentation through photographs, and vehicle counts recorded alongside relevant sketches for analysis. Secondary data were sourced from published and unpublished materials on transportation and parking management, as well as official reports and policies from the Nasarawa Urban Development Board (NUDB). This included existing regulations, standards, and operational frameworks, such as pricing structures, timing, and fee management.

3.3. Sampling and Study Design

The sample frame comprised eight clusters representing various public spaces, including educational institutions, religious centers, banks, malls, markets, hotels, offices, and healthcare facilities. Each cluster was divided into two study points, monitored at two-hour intervals to capture vehicle usage durations within specific parking bays or lots.

A total of 1,167 parking lots were identified across these clusters. Purposive sampling was employed to focus on public areas experiencing high parking demands. A total of 383 questionnaires were administered, with 328 valid responses obtained, representing a consistent sample of parking facility characteristics.

3.4. Data Analysis

Data analysis involved descriptive statistical methods, ensuring reliability through SPSS software. The internal consistency of the collected data was validated with a Cronbach's Alpha score of 0.784, indicating strong reliability. Results were presented using frequency tables and pie charts to illustrate parking adequacy, usage patterns, and parking methods. Furthermore, mean

rank analysis to identify critical issues, where lower means indicated significant problems requiring urgent intervention, while higher means suggested fewer pressing concerns.

4. RESULTS AND DISCUSSION

4.1. Level of Provision and Existing Situation

This section evaluates the current level of provision and existing conditions of public parking facilities in Keffi's selected areas. Several key indicators including parking accumulation, capacity, load, and index were examined using responses from 328 valid questionnaires, representing a response rate of 85.6% from the total 383 administered.

Table 1 provides an overview of the gender distribution among respondents. The findings reveal that 91.5% of participants were male, while only 8.5% were female. This gender imbalance suggests that male respondents may dominate parking usage and perspectives in the study area, potentially influencing parking-related behaviours and perceptions.

Table 1 Gender of the Respondents

Gender	Frequency	Percentage (%)
Male	300	91.5
Female	28	8.54
Total	328	100

4.2. Parking Accumulation in Public Parking Facilities

The disparity between parking demand and available spaces is highlighted in Table 2, which presents parking accumulation data for various public facilities. Observations conducted over an 8-hour window (8 a.m. to 4 p.m., Monday to Friday) indicate that the Federal Medical Centre, Keffi recorded the highest surplus vehicles, with 3,199 parked vehicles against a capacity of only 151 spaces, resulting in a significant shortfall of 2,640 vehicles.

On the other hand, ECWA 1 recorded the lowest parking surplus, with 19 surplus vehicles, reflecting a smaller gap between supply and demand. These findings underscore the widespread inadequacy of parking spaces across the study area, with most facilities falling short of the NUDB parking standards, contributing to persistent parking congestion and inefficiencies.

Table 2 Parking Accumulation

S/No	Location	Time (8Hr) Mon-Fri	Total Parked Vehicle Count	Maximum Parking Capacity	Surplus Vehicles
1	Nasarawa State University Keffi	8 am – 4 pm	4.158	688	718
2	Federal Government College	8 am – 4 pm	72	0	72
3	NPF Area Command HQ	8 am – 4 pm	126	2	116
4	Nig. Security & Civil Defence Corp	8 am – 4 pm	37	0	37
5	New Market Keffi	8 am – 4 pm	930	75	555
6	Old Market Keffi	8 am – 4 pm	1,053	86	623
7	Access Bank Keffi	8 am – 4 pm	391	17	306
8	First Bank of Nig	8 am – 4 pm	536	17	431

S/No	Location	Time (8Hr) Mon-Fri	Total Parked Vehicle Count	Maximum Parking Capacity	Surplus Vehicles
9	AGY Plaza	8 am – 4 pm	752	41	520
10	Halibiz Plaza	8 am – 4 pm	415	10	355
11	Atlantic Hotel	8 am – 4 pm	90	6	60
12	Sawalino Hotel	8 am – 4 pm	535	55	260
13	Federal Medical Centre, Keffi	8 am – 4 pm	3,199	151	2,640
14	Nagari Hospital	8 am – 4 pm	95	5	70
15	Central Mosque	8 am – 4 pm	889	10	849
16	ECWA 1	8 am – 4 pm	67	10	19

Source: Authors' Field Work, 2022

4.3. Parking Capacity Across Locations

Parking capacity analysis reveals notable disparities across various locations, as summarized in Table 3. Nasarawa State University Keffi provides the highest parking capacity with 688 spaces, yet this still fails to meet demand. By contrast, Federal Government College Keffi and the Nigeria Security and Civil Defence Corps lack any designated parking facilities, representing a complete deviation from planning standards set by NUDB.

These discrepancies highlight the critical need for standardized parking provisions to meet the growing demand for spaces in Keffi's public facilities. The calculated parking index further emphasizes the inadequacies across most locations, pointing to an urgent requirement for regulatory enforcement.

Table 3 Parking Capacity

S/No	Location(s)	No. of Parking Space	Percentage (%)
1	Nasarawa State University Keffi	688	59
2	Federal Government College	0	0
3	NPF Area Command HQ	2	0.17
4	Nig. Security & Civil Defence Corp	0	0
5	New Market Keffi	75	6.4
6	Old Market Keffi	86	7.4
7	Access Bank Keffi	17	1.5
8	First Bank of Nig	17	1.5
9	AGY Plaza	41	3.5
10	Halibiz Plaza	10	0.9
11	Atlantic Hotel	6	.05
12	Sawalino Hotel	55	4.7
13	Federal Medical Centre, Keffi	151	12.9
14	Nagari Hospital	5	0.4
15	Central Mosque	10	0.9
16	ECWA 1	10	0.7
	TOTAL	1167	100

Source: Field Work, 2022

4.4. Parking Load Across Location

Parking load refers to the number of spaces occupied within a specified period. As shown in Table 4, data collected during a 4-hour window (8 a.m. to 12 p.m.) revealed peak occupancy levels, providing insights into parking demand intensity. Nasarawa State University Keffi recorded the highest load with 430.5 vehicles (32.8%), followed closely by the Federal Medical Centre Keffi at 381.5 vehicles.

This data highlights pressure points where peak parking demand far exceeds available capacity, emphasizing the need for strategic interventions to manage vehicle accumulation during busy hours.

Table 4 Parking Load

S/No	Location(s)	Total Vehicle Count in 4 Hours (8am – 12pm)	Percentage (%)
1	Nasarawa State University Keffi	430.5	32.8
2	Federal Government College	7.5	0.6
3	NPF Area Command HQ	15.5	1.2
4	Nig. Security & Civil Defence Corp	3.5	0.3
5	New Market Keffi	86.5	6.6
6	Old Market Keffi	100.5	7.7
7	Access Bank Keffi	31	2.4
8	First Bank of Nig	47	3.6
9	AGY Plaza	79.5	6.1
10	Halibiz Plaza	28	2.1
11	Atlantic Hotel	8.5	0.6
12	Sawalino Hotel	54.5	4.1
13	Federal Medical Centre, Keffi	381.5	291.1
14	Nagari Hospital	10	0.7
15	Central Mosque	31	2.4
16	ECWA 1	6	0.5

Source: Authors' Field Work, 2022

4.5. Parking Index Across Locations

The parking index, or occupancy ratio, measures the effectiveness of parking facility utilization across the selected locations. Table 5 shows that Nasarawa State University Keffi and the Federal Medical Centre Keffi exhibit the highest utilization rates, at 62.6% and 55.5%, respectively. These values fall within the "Enough" category (50%-75%), indicating moderately effective use of parking resources relative to demand.

In contrast, facilities like the Nigeria Security and Civil Defence Corps recorded a parking index of 0.51%, reflecting severe underutilization and insufficient availability. The index classification is defined as:

- "Good": Above 75% (optimal utilization),
- "Enough": Between 50% and 75% (moderate adequacy), and
- "Less": Below 50% (poor utilization).

The analysis reveals that most locations in Keffi fall within the "Less" category, underscoring a widespread mismatch between parking demand and supply. Better alignment with demand requires targeted interventions to optimize parking capacity and ensure effective utilization, particularly in high-demand areas.

Table 5 Parking Index on Utilization

S/No	Location(s)	Maximum Parking Capacity	Average Parking Load	Parking Index (%)
1	Nasarawa State University Keffi	688	430.5	62.6
2	Federal Government College	0	7.5	1.09
3	NPF Area Command HQ	2	15.5	2.25
4	Nig. Security & Civil Defence Corp	0	3.5	0.51
5	New Market Keffi	75	86.5	12.6
6	Old Market Keffi	86	100.5	14.5
7	Access Bank Keffi	17	31	4.5
8	First Bank of Nig	17	47	6.8
9	AGY Plaza	41	79.5	11.56
10	Halibiz Plaza	10	28	4.1
11	Atlantic Hotel	6	8.5	1.2
12	Sawalino Hotel	55	54.5	7.9
13	Federal Medical Centre, Keffi	151	381.5	55.5
14	Nagari Hospital	5	10	1.5
15	Central Mosque	10	31	4.5
16	ECWA 1	10	6	8.9

Source: Authors' Field Work, 2022

4.6. Compliance with Standard Space Requirements and Parking Management

This subsection evaluates compliance with parking space standards and management practices as stipulated by the Nasarawa Urban Development Board (NUDB). According to the 2015 Development Control Standard and Regulation, 20% of total developed land should be allocated to parking facilities.

Table 6 highlights significant non-compliance across most locations. Only 31.2% of surveyed locations meet the minimum requirement, while 68.8% fall short. For example, Nasarawa State University Keffi requires 1.74 hectares for parking but currently provides only 0.86 hectares. Similarly, institutions like the Federal Government College lack any allocated parking space, reflecting a complete deviation from the prescribed standards.

These findings align with previous studies by Dada et al. (2023) and Joel et al. (2022), which identified similar trends of non-compliance in Minna, Niger State, and Oyo State, respectively. Addressing these gaps requires stricter enforcement of regulatory standards to ensure sufficient land allocation for parking facilities. Effective management and compliance will mitigate congestion and enhance urban mobility.

Table 6 Distribution of Land Coverage for Parking

S/No	Location(s)	Land Coverage (Ha)	20% Required Land for Parking	Land Coverage for Parking	Difference
1	Nasarawa State University Keffi	87.2	1.74	0.86	0.21
2	Federal Government College	1.1	0.22	0	0.22
3	NPF Area Command HQ	0.85	0.17	1.0025	0.0025
4	Nig. Security & Civil Defence Corp	0.25	0.05	0	0.25
5	New Market Keffi	8.2	1.6	0.94	0.12
6	Old Market Keffi	3.8	6.2	1.1	4.92
7	Access Bank Keffi	0.27	0.054	0.021	0.033
8	First Bank of Nig	0.35	0.70	0.021	0.05
9	AGY Plaza	1.21	0.20	0.051	0.15
10	Halibiz Plaza	1.3	0.20	0.0021	0.179
11	Atlantic Hotel	0.28	0.06	0.0075	0.592
12	Sawalino Hotel	2.3	0.41	0.07	0.34
13	Federal Medical Centre, Keffi	19.1	3.8	1.9	1.99
14	Nagari Hospital	0.21	0.42	0.0061	0.036
15	Central Mosque	3.9	0.62	0.013	0.607
16	ECWA 1	0.29		0.013	0.607
	TOTAL	130.6 Ha	16.04 Ha	5.01 Ha	11.03 Ha

Source: Authors' Field Work, 2022

4.7. Parking Management System in the Study Area

The study examined the predominant parking methods employed in Keffi Town, focusing on parallel, angular, and perpendicular parking. As illustrated in Figure 3, parallel parking is the most prevalent method, accounting for 65.2% of observed on-street parking. Angular parking follows at 33.2%, while perpendicular parking accounts for a minimal 1.6%. The dominance of parallel parking is likely due to limited space availability and its suitability for congested urban environments, where ease of maneuverability is prioritized. Figures 4, and 5 further illustrate instances of parallel parking in locations like Halibiz Shopping Mall and the Federal Medical Centre Keffi.

Figure 3 Distribution of Respondent on Parking Method
(source: Field Work, 2022)

Figure 4 Showing Parallel Parking at Halibiz Shopping Mall
(source: Authors' Field Work, 2022)

Figure 5 Showing Parallel Parking at Federal Medical Centre, Keffi
(source: Authors' Field Work, 2022)

4.8. Respondent on Parking Timing and Parking Pricing

The analysis revealed an absence of established regulations regarding parking timing and pricing in Keffi Town. None of the surveyed locations implement structured timing schedules or pricing mechanisms for parking. This lack of regulation encourages **haphazard parking practices**, leading to frequent spillovers and further exacerbating congestion issues.

Moreover, the absence of formal pricing systems represents a missed economic opportunity. A well-regulated parking system could alleviate parking-related challenges by:

- Controlling parking durations,
- Generating revenue for infrastructure development, and
- Creating employment opportunities for local residents.

Structured parking management strategies—such as implementing time-based pricing and enforcing parking durations—are essential for achieving order, reducing congestion, and unlocking economic benefits in urban areas like Keffi.

5. CONCLUSION

The parking challenges in Keffi Town primarily stem from rapid population growth, urbanization, and expanding economic activities. This study reveals significant non-compliance with planning standards meant to regulate parking provisions, despite existing policies and legislative frameworks under the authority of the NUDB. Ineffective enforcement of these standards has led to widespread indiscriminate parking, diminishing the efficiency of the road network and accessibility across public land uses.

Keffi's strategic location as a gateway to Abuja has further exacerbated parking issues. The influx of people, commercial activities, and vehicles has significantly increased the demand for parking facilities, which remain unmet. Many property owners prioritize profit over compliance, resulting in developments that lack adequate parking spaces. The resulting parking congestion is compounded by haphazard parking maneuvers, frequent accidents, and inefficient use of public spaces. These findings align with previous studies, such as those by Dada et al. (2023) and Joel et al. (2022), which reported similar patterns of non-compliance in Minna, Niger State, and Oyo State.

To address parking challenges in Keffi Town, short-term planning and regular reviews of public parking facilities should be conducted, considering factors such as population growth, vehicle ownership rates, and peak-hour demands to ensure parking provisions evolve with urban needs. Additionally, parking infrastructure must account for population shifts resulting from urban development projects to prevent future congestion. Establishing a balanced ratio of on-street and off-street parking, in line with international standards (Ma et al., 2014), will optimize space utilization and minimize indiscriminate parking. Implementing these measures will create a sustainable public environment, enhance urban infrastructure, reduce congestion, and improve accessibility for residents and visitors.

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DEVELOPMENT STRATEGIES FOR GRID-CONNECTED UTILITY-SCALE SOLAR PHOTOVOLTAIC TO INCREASE RENEWABLE ENERGY PENETRATION

Surya Budi Ariyadi[1*], Widodo Wahyu Purwanto[1,2]

[1]*Master Program in Energy Systems Engineering, Department of Interdisciplinary Engineering, Faculty of Engineering, Universitas Indonesia, Depok, 16424, Indonesia*
[2]*Sustainable Energy Systems and Policy Research Cluster, Universitas Indonesia, Depok, 16424, Indonesia*

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ABSTRACT

The government of Indonesia has launched programs to decarbonize its power systems by replacing fossil fuel-based plants with renewable energy. Solar photovoltaic (PV) deployment faces economic and technical barriers despite abundant solar irradiance. This study evaluates techno-economic strategies for 10 MW grid-connected solar PV systems, comparing two scenarios: without Battery Energy Storage System (BESS) and with BESS to reduce grid reliance. Key interventions were analyzed for their economic impacts, including tariff adjustments, carbon tax implementation, and competitive auction schemes. The results show that without BESS, the project achieves an Internal Rate of Return (IRR) of 21.30%, making it highly feasible. However, including BESS lowers the IRR to 5.89% due to higher costs. Combining carbon tax and tariff adjustments improves feasibility, achieving a Profitability Index (PI) of 1.00 and an IRR of 14.74%. Competitive auctions further lower costs, enhancing the feasibility of BESS projects. While solar PV without BESS is economically viable, risks of capital cost increases require attention. For BESS projects, policy interventions such as auctions and incentives are essential. This study highlights strategic measures to accelerate solar PV adoption in Indonesia, providing insights for policymakers and investors to scale up renewable energy deployment effectively.

Keywords: Techno-Economic; Economic feasibility; Power generation strategy; Renewable integration; Solar PV

1. INTRODUCTION

Ratifying the Paris Agreement, Indonesia is committed to reducing greenhouse gas (GHG) emissions. Through its Nationally Determined Commitment (NDC), Indonesia has pledged to reduce GHG emissions by 29% using domestic resources (unconditional) and 41% with international support (conditional) from the business-as-usual scenario by 2030. Additionally, Indonesia aims to reduce GHG emissions by 27.3% compared to the baseline and increase renewable energy (RE) penetration to 20% by 2024 through the National Medium-Term Development Plan 2020-2024 (Sambodo et al., 2022). As part of this plan, the Minister of Energy and Mineral Resources (MEMR) announced the replacement program for 2,246 diesel power plants, 23 coal-fired power stations, and 46 combined cycles power plants with renewable energy sources as a national priority (Hamdi, 2020). This commitment is further reflected in the 2021-2030 Electricity Supply Business Plan (*Rencana Usaha Penyediaan Tenaga Listrik* / RUPTL), which outlines the addition of 40.6 GW of new power plants,

*Corresponding author's email: surya.budi@ui.ac.id, suryabudiariyadi@gmail.com
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with 20.9 GW (51.6%) allocated for renewable energy development, while retiring 1.1 GW of steam-electric power plants and replacing 3.6 GW of outdated diesel/gas plants (PLN, 2021).

Indonesia's current solar energy capacity stands at 1957 MW, accounting for just 1.05% of RE capacity and 0.17% of total installed power generation (IRENA, 2024). Despite its potential of 207,820 MW, Indonesia lags behind regional peers such as India, Korea, Vietnam, Thailand, Malaysia, and Singapore in solar PV deployment (EBTKE, 2018). This discrepancy highlights the urgent need for targeted strategies to unlock Indonesia's solar energy potential by addressing key barriers to deployment.

Renewable Energy (RE) development in Indonesia faces obstacles at three levels: country-level, program-level, and project-level. At the country level, challenges include the dominance of fossil fuels, regulatory uncertainty, and weak alignment between RE planning and procurement. At the program level, barriers include low procurement volumes, unattractive tariff structures, and inefficient processes. At the project level, developers face unclear licensing, land acquisition delays, and financing challenges (Halimatussadiah, 2024).

Regional experiences provide critical insights for overcoming these challenges. In Vietnam, high Feed-in Tariffs (FIT) and tax incentives stimulated rapid solar PV growth (Do et al., 2021). In India, e-reverse auctions significantly reduced costs, though developers faced financing risks due to underestimated capital to decrease the bid price (Bose and Sarkar, 2019). Turkey's hybrid auction model, offering FITs, incentives for local content, land permint and aquisition costs exemption, proved effective in achieving competitive bids (Sirin and Sevindik, 2021). Meanwhile, Korea's computational auction schemes demonstrated that tailored auction designs reduce prices for participants, offering both capacity and price proposals (Jihyeok Jung et al., 2024).

Amir et al. (2022) analyzed the techno-economic and environmental feasibility of a grid-connected solar–biomass hybrid energy system in Madura, Indonesia, which concludes that hybrid systems offer cost-effective and environmentally sustainable solutions for rural electrification. Moreover, Efendi et al. (2024) examined the performance of a Savonius vertical axis wind turbine (SVAWT) under low wind speeds for residential applications, which demonstrates its potential to achieve significant renewable energy contributions when optimized for specific design parameters. Similarly, Umam et al. (2024) conducted a detailed techno-economic analysis of hybrid renewable systems (HRS) combining solar, wind, and biomass energy for an energy-rich rural area in Indonesia, which highlights optimal on-grid and off-grid configurations to reduce emissions and meet local energy demands. However, these studies have not yet analyzed the economic indicators such as the Internal Rate of Return (IRR) and Profitability Index (PI) and addressed the impact of location-specific factors like transmission line costs, carbon tax implementation, and competitive auction schemes on utility-scale solar PV feasibility.

This paper addresses these research gaps by assessing the techno-economic feasibility of 10 MW grid-connected solar PV systems in Indonesia, with scenarios involving Battery Energy Storage Systems (BESS) and non-BESS designs. The study evaluates key interventions, including policy adjustments, transmission line cost impacts, carbon tax incentives, and competitive auction schemes, to propose strategic development measures. This study contributes novel insights into optimizing solar PV deployment strategies in Indonesia by focusing on economic indicators such as IRR and PI.

2. LITERATURE STUDY

2.1. Solar PV Tariff

The electrical energy purchase tariff in Indonesia is set in Presidential Decree No. 112, 2022, concerning the Acceleration of Renewable Energy Development for the Supply of Electric Power. This decree regulated the electrical energy purchase from the Independent Power Producer (IPP) by an off-taker, in this case, State Owned Electricity Company (*Perusahaan Listrik Negara / PLN*). The tariffs refer to the highest reference price or negotiation results and are valid without escalation along the Power Purchase Agreement (PPA) period. Tariffs for solar PV that use electrical energy storage facilities (BESS) will be compensated a maximum of 60% higher than those that do not use the energy storage facilities. Table 1 shows the detailed tariff arrangement for IPP-procured land (Republik Indonesia, 2022).

Table 1 Solar PV Tariff (without BESS)

		Tariff (cents USD/kWh)
Properties	**Year 1 to 10**	**Year 11 – 13**
Up to 1 MW	11,47 x F	6,88
> 1 to 3 MW	9,94 x F	5,97
> 3 to 5 MW	8,77 x F	5,26
> 5 to 10 MW	8,26 x F	4,96
> 10 to 20 MW	7,94 x F	4,76
> 20 MW	6,95 x F	4,17

F denotes the location factor. The research location is Central Java, which was selected based on the considerations below. At least 3 out of the ten largest capacity fossil-based power plants on Java Island are in Central Java: PLTU Tanjung Jati B, PLTU Batang, and PLTU Cilacap (Openinframe, 2024). RE penetration in this area is expected to balance the GHG emission or is further considered to gradually replace the fossil-based power plants. Northern Central Java has suitable irradiation and a relatively large area to be proposed as the project location. According to State Owned Electricity Company (*Perusahaan Listrik Negara* / PLN) statistics, the installed capacity of solar PV in Central Java up to 2023 remains below other provinces (PLN, 2023). The location factor (F) of Central Java is 1.

All of those tariff requirements, terms, and conditions will be set in the PPA, a long-term contract between the IPP and the off-taker. The PPA provides a stable and predictable revenue stream for the IPP and a reliable, low-cost electricity supply for the consumers (Raza, 2023). The PPA could be the key to the bankability of the RE project (Irena, 2018). Specified tariffs in the PPA could be “Take or Pay” or “Take and Pay” (merchant offtake). Under the “Take or Pay” scheme, the buyer/off-taker must pay for any produced energy at a predetermined time according to the specified volume in the contract, regardless of whether the buyer utilizes the electrical energy. Under the “Take and Pay” scheme, the buyer/off-taker is required to take and pay a minimum amount of determined energy at a price according to the provisions of the contract; in the event the buyer does not take it, it will be considered a contract breach (Ehanmo, 2021).

2.2. Carbon Tax

Carbon trading is regulated in Presidential Regulation No. 98 of 2021 concerning implementing the Economic Value of Carbon (NEK) to achieve Nationally Determined Contribution (NDC) targets and control GHG emissions. NEK implementation is carried out through carbon trading mechanisms, carbon levies, performance-based payments, and other mechanisms. The carbon trading mechanism will be carried out through the Indonesian carbon exchange (Republik Indonesia, 2021).

A carbon tax is further regulated in Law No. 7 year of 2021 concerning the harmonization of tax regulations. A carbon tax is imposed on carbon emissions that have a negative impact on the environment. The carbon tax rate is higher or equal to the carbon price in the carbon market per kg CO_{2e}. If the carbon price in the market is lower than IDR 30.00 per kg CO_{2e}, the tariff is set at a minimum of IDR 30.00 per kg CO_{2e} (Republik Indonesia, 2021). The price of CO_2 on the Indonesian carbon exchange as of April 2024 is IDR 58.8/kg CO_{2e} (IDX Carbon, 2024). A rounded carbon tax value of IDR 60.00/kg CO_{2e} (USD 3.64/ton CO_{2e}) is used to simplify. The rate has complied with the regulation. To get the total tax incentive per year, the carbon price is multiplied by the total replaced CO_2 emission per year; in this case, the fossil-based emission factor in kg CO_{2e}/MWh multiplied by the renewable energy production in MWh per year.

Finland was the first country in the world to implement a carbon tax. Nowadays, not less than twenty-five countries around the globe have implemented a carbon tax. The carbon tax of Finland is USD 99.98/ton CO_{2e}. Other Asia countries, Japan and Singapore, are implementing carbon taxes of USD 1.9/ton CO_{2e} and USD 18.47/ton CO_{2e}, respectively. At the same time, Uruguay implemented the highest carbon tax, which is USD 167.17/ton CO_{2e} (Statista, 2024).

2.3. Solar PV Auction

From 2010 to 2022, utility-scale solar PV showed a significant reduction in global weighted average LCOE of 89% from USD 0.445/kWh to USD 0.049/kWh. This was influenced by a decrease in the price of solar panel modules by around 45%, soft costs (costs not directly related to construction costs) by around 14%, and construction/EPC costs by around 12%. The LCOE of Indonesia's utility-scale solar PV in 2022 ranges from USD 4.09 – 10.09/kWh. LCOE for utility-scale solar PV with a minimum capacity of 10MW is USD 5.8 cents/kWh (Putranto et al., 2022; IRENA, 2023; IESR, 2019).

LCOE results from competitive auctions for global solar PV PLTS show a decreasing trend, and the value is below the LCOE procurement without using competitive auctions. The global average LCOE from the 2021 auction is USD 0.039/kWh. For 2019, the average LCOE was USD 0.068/kWh, while the competitive auction result was USD 0.052/kWh. In line with previous research (Do et al., 2021; Bose and Sarkar, 2019; Sirin et al., 2021; Jihyeok Jung et al., 2024) showing that competitive auctions could obtain low bid prices, research in Africa and Brazil also shows a similar trend. Africa auctions during that required material prequalification, financial prequalification, and the application of sanctions obtained (obtained or "resulting a") bid price of 75% below the global LCOE. The hybrid descending clock auction in 2014 in Brazil succeeded in getting a bid price of 17% below the upper limit price with the condition that the transmission line cost is out of the IPP's responsibility (Sirin and Sevindik, 2021; Viana and Ramos, 2018). Generally, it can be considered that auctions create competition in which IPPs compete to provide the best and cheapest offers within their limit. Therefore, auction results tend to be competitive and low.

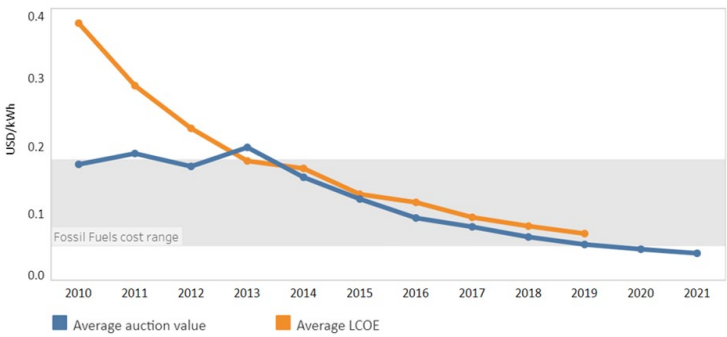

Figure 1 Average LCOE and Auction Values (IRENA, 2020)

IRENA (2020) summarizes the results of solar PV auctions from various countries and is presented in Figure 1 below. In 2019, it was shown that the LCOE from the auction was USD 0.052/kWh, whereas without the auction, it was USD 0.068/kWh.

2.4. Transmission Cost

In the event that the solar PV location is at a certain distance from the load source or off-taker, which requires the construction of a transmission line from the generator to the nearest off-taker transmission line, there will be additional costs for development and operational for utilizing the off-taker transmission line. The transmission line development for 150 kilo volt High Voltage Overhead Line (SUTT) costs about IDR 3.63 billion/km. While the operational cost could adopt the Power Wheeling concept, using the "MW-Mile Bialek Tracing" method. Bialek Tracing is a method for calculating transmission line rental costs. The calculation of transmission line rental costs considers losses and the amount of power on the sending and receiving sides of the line. The MW-Mile Bialek tracing method uses the actual transmission line. The power calculation used for this method uses the average power between the sent and received power on the line. The power wheeling cost for capacities of 50 MW, 100 MW, and 200 MW is IDR 37.39/kWh, IDR 71.64/kWh, and 201.52/kWh, respectively (Galih et al., 2015; PLN, 2021).

3. METHOD

This study evaluates the techno-economic feasibility of developing grid-connected, ground-mounted, utility-scale solar PV systems with and without BESS. The methodology comprises four main stages: (1) identifying the case study location and project parameters, (2) optimizing the solar PV and BESS design using HOMER Pro software, (3) developing and simulating economic intervention scenarios, and (4) performing economic feasibility analyses using key indicators.

3.1. Case Study

The solar PV project has a 10 MW capacity, located in the vicinity of PLTU Tanjung Jati B in Central Java, at coordinates Latitude -6.451179° (6°27'04.2"S) and Longitude 110.732709° (110°43'57.8"E), as shown in Figure 2.

Figure 2 Study Location (Google Map, 2024)

The location was selected for the several reasons: Central Java is home to three of the largest fossil-based power plants in Indonesia—PLTU Tanjung Jati B, PLTU Batang, and PLTU

Cilacap—making it a strategic location for renewable energy integration. The region has high solar irradiation potential, making it suitable for utility-scale solar PV development. Northern Central Java has abundant land availability, ensuring cost-effective project implementation. The installed solar PV capacity in Central Java remains low compared to other regions (PLN, 2023), therefore, there is a potential for growth.

The project assumes proximity to the off-taker's transmission network, eliminating additional transmission line costs and rental fees. The project is using project financing with 70% capital is financed by loans and the rest of 30% capital is by IPP. The PPA tariff is set with adherence to the government regulation of Presidential Decree no. 112 year of 2022. The payment scheme is Take or Pay for the first twenty years and Take and Pay for the rest of the period. The PPA is for 25 years without any escalation. The IPP offers the capacity commitment for off-taker approval. This capacity commitment is set based on IPP pre-assessment, which considers plant capacity and irradiation. However, all produced electricity is distributed to the grid.

3.2. Design System

The first step in the system design process is to determine the capacity commitment to be offered in the PPA. This is achieved through the first-round modelling using HOMER Pro software. The objective is to obtain the PV output for the specified study location (latitude: -6.451179°, longitude: 110.732709°). The PV module specifications used in the simulation are shown in Table 2, which are consistent with modern high-efficiency monocrystalline PV modules commonly deployed in utility-scale projects (NREL, 2023; Goldman Sachs, 2024). Average hourly PV output per month is set as the load model, and the model is adjusted in multiples of 5% reductions to meet these design criteria: no excess electricity (to minimize waste), no unmet electric load or capacity shortage, and the grid purchases limited to 5% of total PV output. Load models meeting the above criteria are then set as the capacity commitment and designated as the AC primary load for the final system model.

Table 2 Solar PV Module Specifications

Properties	Value
Maximum Power / Pmax (Wp)	425
Power tolerance	0 ~ +3 %
Derating factor (%)	80.00
Product Warranty / lifetime (years)	25.00
Efficiency / ηPV (%)	21.80
Voltage at Max. Power / VMP (Volt)	31.94
Current at Max. Power / IMP (A)	13.31
Open Circuit Voltage / VOC (Volt)	37.96
Short Circuit Current / ISC (A)	14.08
Operating Temperature (°C)	-40 ~ +85
Maximum System Voltage (VDC)	1500
Dimension (mm)	1722x1134x30
Weight (kg)	20.80

The second round of modelling is developed based on capacity commitment as AC primary load and chosen PV module specification. HOMER Pro is required to propose the most optimum design of inverter and BESS. Adjustment of inverter and BESS capacity can be done to meet criteria of no excess electricity, no unmet electric load, no capacity shortage and now for the amount of grid purchase shall be below 1% (design is ordered to move the grid purchasing into BESS usage optimization). The simulation results in optimum technical design.

The capital expenditure (CAPEX) of the modelling is based on Focused Group Discussion (FGD) data between the Indonesian Ministry of Finance with the solar PV developer association in Indonesia and adjusted (extrapolated) to get the 2024 cost. While the CAPEX for BESS is USD 446.27/kWh (battery hardware of USD 270/kWh and projected decrease to USD 69/kWh) (Fiscal policy Agency, 2018; Directorate General of Electricity, 2021; NREL, 2023; Goldman Sachs, 2024). Table 3 shows the CAPEX of the design.

OPEX for Indonesia is assumed to use the Asian region range. Based on 2023 data, the OPEX value for the development of utility-scale solar PV for Asia is USD 3.60/kW/year. OPEX for 4 hours storage capacity BESS in 2022 is USD 44.6/kW/year. For 2024, the OPEX is projected to fall to USD 40,969/kW/year. This OPEX consists of Fixed Operational & Maintenance (FOM) and Variable Operational & Maintenance (VOM), where the VOM is assumed zero (NREL, 2023; Goldman Sachs, 2024). Table 3 shows the CAPEX and OPEX of the design. Other economic parameters used in economic analysis are shown in Table 4.

Table 3 Solar PV Module

Component	Without BESS			With BESS		
	CAPEX (USD)	OPEX (USD)	Replacement (USD)	CAPEX (USD)	OPEX (USD)	Replacement (USD)
Solar PV	528.210	2.105	-	528.210	2.105	-
Inverter	76.413	0.304	46.776	76.413	0.304	46.776
System fixed capital	83.779	1.194	-	83.779	1.194	-
BESS	-	-	-	277.046	10.243	226.896
Total	688.402	3.603	46.776	965.448	13.846	273.672

Table 4 Economic Parameters

Parameters	Value	References
Loan rate (loan in USD)	6,60%	annually (Bank of Indonesia, 2024)
Loan period	10	Years
Discount rate	6,25%	(Bank of Indonesia, 2024)
Corporate tax	22,00%	(Indonesia Law No.7, 2021)
Expected rate of return	15%	(hurdle rate)

3.3. Development Scenario

Several interventions representing regulation, fiscal incentive, technical aspects, and procurement scheme are applied to exercise the impact on the project economic feasibility. Scenario 1.a. is as the base scenario of without BESS system. To examine the Scenario 1.a. sensitivity to the additional cost required for transmission line development and fee when the plant location is in a distance to the off-taker location is set as Scenario 1.b. Scenario 2.a. is as the base scenario of with BESS system as backup and to minimize the grid purchase. Interventions of carbon tax and competitive auction scheme are applied as Scenario 2.b. and Scenario 2.c. respectively. The implementation of carbon tax becomes additional revenue for the IPP that could restructure the cash flow. Meanwhile, competitive auction intervention is examined to see the projected economic feasibility when the development is carried out through an auction process. Tariff adjustment is applied to all scenarios where the mentioned interventions have not been able to improve the economic feasibility. If these interventions are insufficient to improve economic feasibility, tariff adjustments are applied across all scenarios. Table 5 shows the scenarios.

Table 5 Scenarios

Scenario	Tariff (as per Regulation)	Transmission	Carbon Tax	Competitive Auction
1.a. Without BESS	√	-	-	-
1.b. Without BESS	√	√	-	-
2.a. With BESS	√	-	-	-
2.b. With BESS	√	-	√	-
2.c. With BESS	√	-	-	√

3.4. Economic Calculation

The following economic indicators are used to assess project feasibility:

3.4.1. Weighted Average Cost of Capital (WACC)

WACC is the average rate of return that a company must provide to investors so that investors want to invest their capital in the company. WACC is used as an instrument for making decisions regarding investment for financing new projects or business development where the returns from these activities must be higher than the WACC. If the project's IRR is greater than WACC, it means that the project investment is profitable. Conversely, if the IRR is lower than the WACC the project investment is not profitable (Cerdasco, 2022). WACC is calculated as shown in Equation 1 below.

$$WACC = \frac{(E_{mv} \times r_e) + [(D_{mv} \times r_d) - (D_{mv} \times r_d \times T)]}{(E_{mv} + D_{mv})} \tag{1}$$

$$r_e = RF + \beta i[E(RM) - RF] \tag{2}$$

where, E_{mv} denote market value of equity, D_{mv} denote market value of debt, r_d denote cost of debt, r_e denote cost of equity, T denote corporate tax rate, RF denote risk-free rate, βi denote beta of stocks, and $E(RM)$ denote expected rate of return.

3.4.2. Discounted Cash Flow

Discounted Cash Flow (DCF) is a way to assess an investment based on projected cash flows in the future using Net Present Value (NPV) calculations by using discount rate that consider rate of return on debt and equity. NPV will provide an overview of the projected value of annual cash flows to the current value (Street of Wall, 2013).

$$NPV = \sum_{y=1}^{y=n} \frac{NCF_y}{(1+i)^y} \tag{3}$$

y is the representative year, NCF denote net cash flow (the sum of cash in and cash out), and i is the discount rate used.

3.4.3. Profitability Index

It is a comparison between the profit (NPV) obtained from investing in a project with the initial investment costs. If PI > 1, the project is considered feasible. Conversely, if PI < 1, then the project is considered not feasible (Sutan et al., 2020).

$$PI = \frac{NPV}{Initial\ Cost} \tag{4}$$

3.4.4. Payback Period (PP)

Payback Period is a parameter that shows the time needed for a project to reach NCF value equal to zero, income is able to cover expenses (Sutan et al., 2020).

$$PP = n + \frac{a - b}{c - b} \times 1\ year \tag{5}$$

n denote the last year that sum of net cash flow amount is minus, $(a - b)$ denote $\sum NCF$ up to year-n (USD), and $(c - b)$ denote the NCF year $(n + 1)$.

3.4.5. Internal Rate of Return (IRR)

IRR is a parameter that provides information about an investment's potential return on capital. It is obtained by iterating the interest rate (i), which gives positive and negative NPV values (Sutan et al., 2020).

$$IRR = i_1 + \frac{NPV_{(+)}}{(NPV_{(+)} - NPV_{(-)})} \times (i_2 - i_1) \tag{6}$$

3.4.6. CoC for Auction

Calculating the Cost of Capital (CoC) from the RE auction result is done by doing a reverse-engineer of the Levelized Cost of Electricity (LCOE) or awarded price (PPA). Assuming that the margin is very small, PPA equals to LCOE. The LCOE is obtained by multiplying CAPEX with CRF and adding with the OPEX where all of these are divided by the multiplication of capacity factor with 8760 (hours in a year). Based on above, we can obtain the CRF. Based on given LCOE and CRF, the CoC can be obtained using equation (7) below (Egil et al., 2023).

$$CRF = \frac{CoC \times (1 + CoC)^t}{(1 + CoC)^t - 1} \tag{7}$$

CRF is the capital recovery factor and t is the total lifetime of the project.

4. RESULTS AND DISCUSSION

4.1. Technical Analysis

The monthly PV output based on HOMER Pro simulation for the selected location and determined solar PV capacity is 14,510,265 kWh/year. The modelling load that meets the design criteria, limiting the purchase of electricity energy from the grid resulting in grid purchases of around 5%, is 70% of the average monthly PV output in a year, determined as capacity commitment. The annual capacity commitment is 10,157,184 kWh/year.

The optimum main components of the solar PV according to HOMER Pro simulation for "Without BESS" scenario include PV modules with a capacity of 424 Wp, a service life of 25 years, and a 1 string inverter with a capacity of 8MW 750-1250 VDC with a service life of 15 years. The results indicate that under this configuration, grid purchases account for 134,631 kWh/year, or approximately 0.92% of total production. The remaining energy consumption is fulfilled by the PV system, while excess energy—representing 28.9% of total production—is sold back to the grid. The lack of an energy storage system results in grid dependence during peak demand periods when load exceeds production capacity.

For the "With BESS" scenario that incorporates a BESS into the system design significantly reduces grid reliance. The HOMER Pro model specifies the addition of a Li-Ion battery with A storage capacity of 22.5 MWh (600V). A service life of 15 years.

Table 6 summarizes the results, clearly showing the differences in production, grid purchases, and energy throughput for both scenarios.

Table 6 Technical Analysis Result

Technical Analysis Result	With BESS		Without BESS	
Production	100.0%	15,284,471.00	100.0%	14,644,896.00
Solar PV Output (kWh/year)	94.9%	14,510,265.00	99.1%	14,510,265.00
Grid purchase (kWh/year)	5.07%	774,206.00	0.92%	134,631.00
Consumption	100.0%	14,994,266.00	100.0%	14,288,363.00
Primary Load (kWh/year)	67.7%	10,157,184.00	71.1%	10,157,184.00
Grid sales (kWh/year)	32.3%	4,837,082.00	28.9%	4,131,179.00
BESS		NA		687,931.00
Throughput (kWh/year)		NA		687,931.00
Fulfilled Capacity Commitment		10,157,184.00		10,157,184.00

The capacity commitment of 10,157,184 kWh/year is achieved with the support of grid purchases amounting to 774,206 kWh/year, or approximately 5.07% of the total electrical energy production from the solar PV power plant. This is illustrated in Figure 3, which depicts the energy profile for the "Without BESS" scenario. The grid purchases align with the initial system design, which limits grid dependency to 5%. Grid purchases are necessary to address shortfalls when the load exceeds PV production during specific periods. Since this scenario lacks an energy storage system, these deficiencies must be fulfilled by the grid. Conversely, when PV production exceeds the load, the surplus energy is exported to the grid, resulting in grid sales.

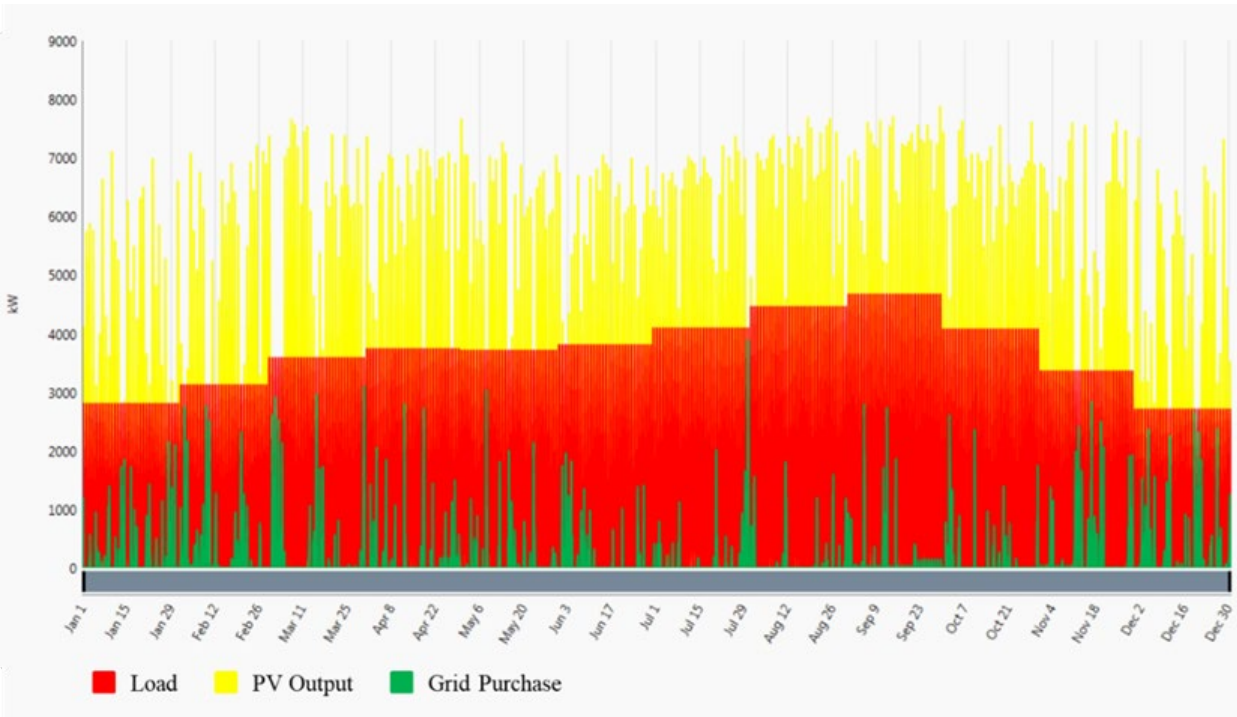

Figure 3 Electrical Energy Profile (Without BESS)

In the "With BESS" scenario, the integration of a Battery Energy Storage System (BESS) significantly minimizes grid purchases. The battery stores surplus PV energy during periods of high production and supplies it during times of excess demand. This reduces grid purchases to 134,631 kWh/year, or approximately 0.92% of the total electrical energy production, as shown

in Figure 4. The battery's total throughput for this scenario is 687,931 kWh/year, indicating its crucial role in balancing supply and demand.

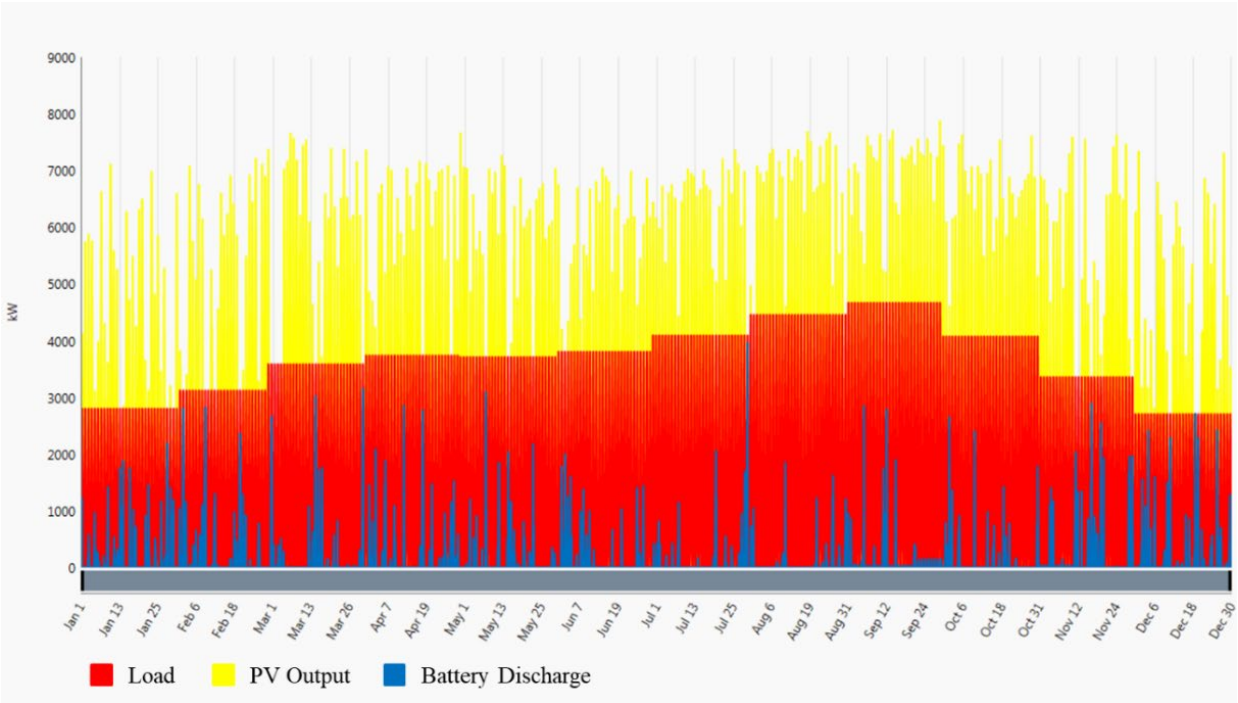

Figure 4 Electrical Energy Profile (With BESS)

Figure 5 provides a detailed view of the energy profile on a specific day (January 16), highlighting how the battery operates in real-time. During the daytime, when PV production exceeds the load, the battery stores excess energy. Later, during periods of insufficient PV production, the stored energy is discharged to meet the load, thereby minimizing grid dependency. This operational behaviour illustrates the battery's effectiveness in addressing the deficiencies seen in the "Without BESS" scenario.

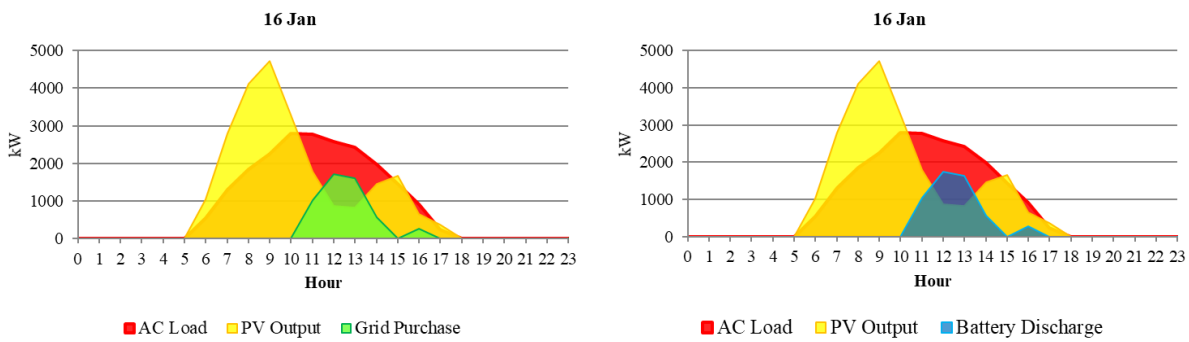

Figure 5 A Sample – Electrical Energy at 16 Jan

The comparison between the two scenarios demonstrates the critical role of BESS in achieving energy reliability and optimizing system performance. While the "Without BESS" scenario relies heavily on grid support, the "With BESS" scenario significantly enhances energy independence and reduces surplus energy exported to the grid.

4.2. Economic Analysis

4.2.1. Without BESS

The economic analysis for the "Without BESS" scenario, shown in Figure 6, demonstrates strong economic feasibility. The project achieves a NPV above zero, a PI above one, and an IRR of 21.30%, which exceeds the expected rate of return of 15%. These indicators confirm the project's financial viability under the current regulatory framework.

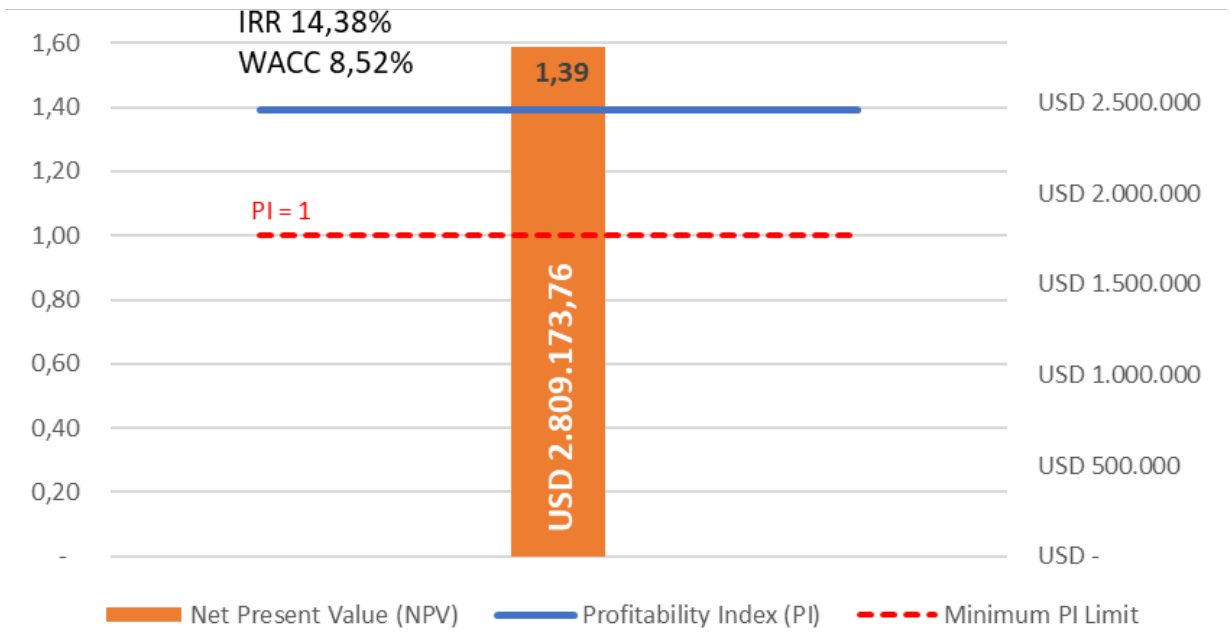

Figure 6 Economic Indicators of Without BESS and Intervention

The payback period for this scenario, as shown in Figure 7, is 4 years and 10 months. It means that the initial investment is recouped relatively quickly. This aligns with findings from similar renewable energy projects in Southeast Asia, where grid-connected solar PV systems without storage exhibit short payback periods due to low capital costs and consistent solar irradiation. The results highlight the feasibility of solar PV systems in Indonesia when energy storage is not included, although this comes with higher reliance on grid purchases to meet energy deficits.

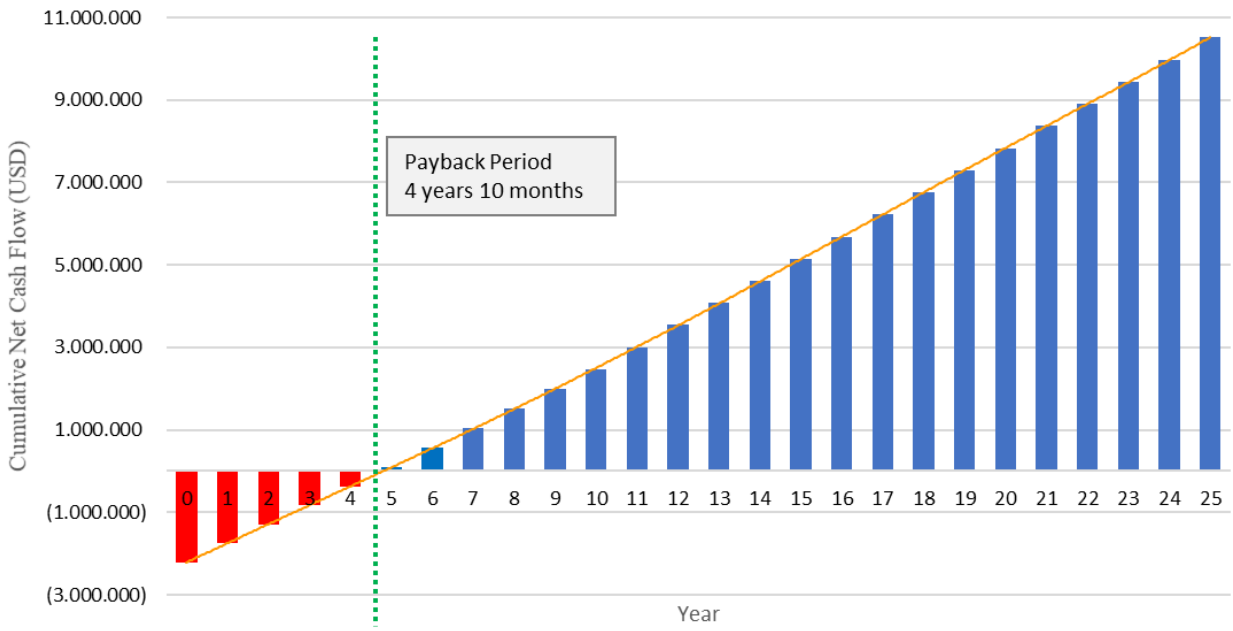

Figure 7 Discounted Cash Flow of Without BESS and Intervention

4.2.2. Transmission Distance Impact

In cases where the plant is located far from the off-taker or load source, additional transmission line investments are required. Transmission costs consist of transmission line construction (CAPEX), USD 244,200.00/km and transmission line rental fee for utilization of the off-taker's

transmission line (OPEX) USD 0.069/kWh (USD 10,400.00/year). The CAPEX is obtained based on historical data of the construction cost in 2021 which is USD 3.63/km as per study of (PLN, 2021) and calculated towards 2024 by an inflation rate of 3.5% per year. While the OPEX is obtained from the extrapolation of transmission rental cost based on MW-Mile Bialek Tracing method for 50 MW and 100 MW (Galih et al., 2015).

These additional costs significantly impact the project's economic indicators. As the transmission distance increases, capital expenditure rises proportionally, reducing economic feasibility. For every 1 km of transmission line added, the NPV decreases by 13.44%.

The project remains economically feasible (PI > 1) only for transmission distances under 4 km. Beyond this, the project's feasibility diminishes unless interventions such as tariff adjustments or subsidies are introduced. If the IPP is willing to accept a PI below one, a positive NPV can still be achieved for transmission distances of up to 16 km. This highlights the importance of proximity to the off-taker when selecting project locations. The impact of transmission distance on economic indicators is shown in Figure 8.

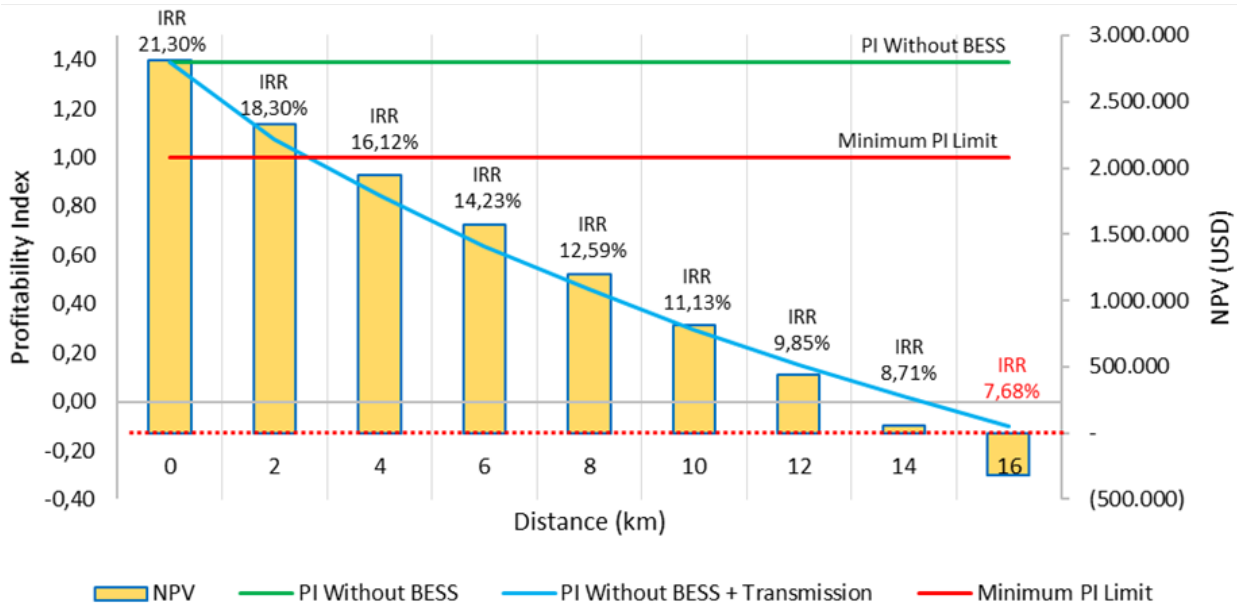

Figure 8 Transmission Impact

4.2.3. With BESS

Using BESS significantly increases the project's capital expenditure, resulting in a negative NPV of USD -1.65 million under the base tariff scenario (see Table 7). This result reflects the high upfront investment costs associated with BESS, which exceed the revenue generated under existing tariff regulations.

However, the project becomes economically feasible with a 39.20% tariff adjustment, which raises the NPV to USD 3.89 million, achieves a PI of 1.00, and delivers an IRR of 14.79%. The payback period, as shown in Figure 9, is 6 years and 8 months, which is longer than the "Without BESS" scenario due to the additional storage costs.

The results align with global studies showing that tariff incentives are critical for improving the economic feasibility of renewable energy projects with energy storage. For instance, countries like Vietnam have successfully used Feed-in Tariffs (FITs) to promote BESS deployment (Do et al., 2021).

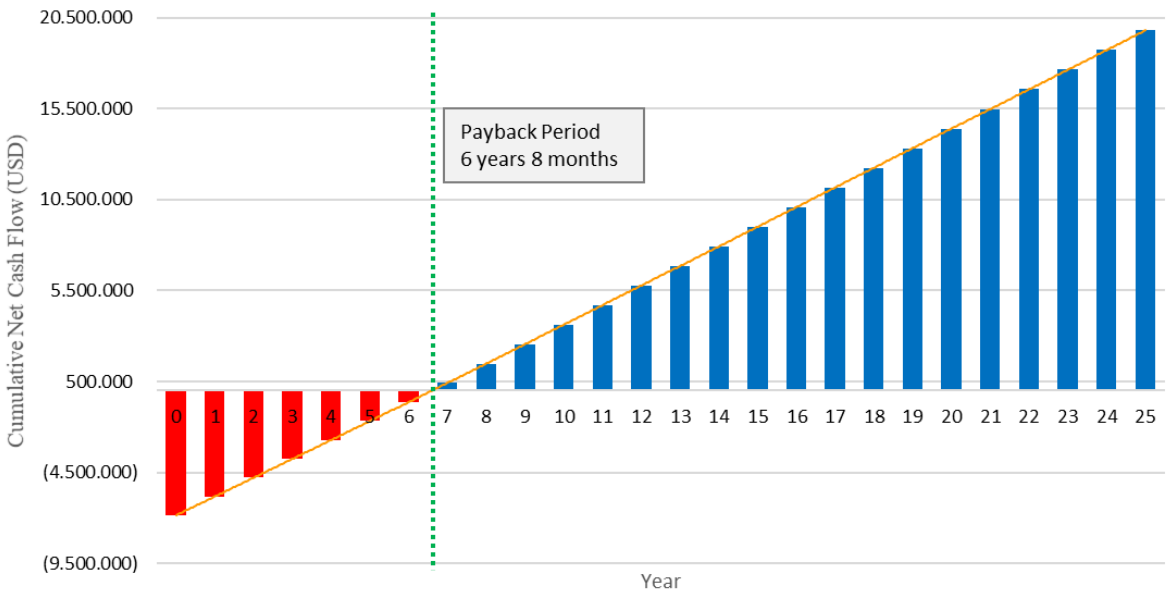

Figure 9 Discounted Cash Flow of With BESS and Tariffs Adjustment

4.2.4. Carbon Tax Impact to With BESS Scenario

The carbon tax rate applied in this study, based on Law No. 7 of 2021, is determined at USD 3.64/ton CO2e (IDR 60,000/ton CO2e). Using an emission factor of 0.80 CO2e/kWh for the JAMALI (Jawa – Madura – Bali) power plants, the annual carbon tax incentive amounts to USD 41,566.15/year, derived from the project's annual electricity production.

Despite this incentive, the carbon tax at the current rate does not sufficiently improve the project's economics. For the project to achieve positive financial indicators (NPV > 0 and PI > 1), the carbon tax rate needs to increase to a minimum of USD 47.4/ton CO2e (IDR 862,000/ton CO2e). This adjusted rate remains reasonable when compared to global standards, falling between the rates in Iceland (USD 36.5/ton CO2e) and France (USD 47.94/ton CO2e). It does, however, exceed carbon tax rates in Japan (USD 1.9/ton CO2e) and Singapore (USD 18.47/ton CO2e) but aligns more closely with the rates implemented by European nations and Canada, where most carbon taxes exceed USD 20/ton CO2e.

Alternatively, if the carbon tax remains at the current rate of USD 3.64/ton CO2e, economic feasibility can still be achieved by increasing the tariff for electricity sales to the off-taker by 36.15%. This adjustment would yield an IRR of 14.74%, effectively improving the project's financial outlook. These findings emphasize the importance of revising carbon tax policies or tariff structures to support renewable energy projects. The detailed economic indicators for this scenario are summarized in Table 7.

4.2.5. Competitive Auction Impact to With BESS Scenario

The reverse-engineering method is used to calculate Cost of Capital (CoC) to determine the effect of auctions on the scenario. Assuming that the PPA or auction price has a very low margin or it is assumed that the PPA price is the same as LCOE. Data set in 2021 used to calculate the CoC are, LCOE non-auction of cents USD 5.1/kWh, LCOE auction of cents USD 3.9/kWh, CAPEX of USD 917.06/kW, OPEX of USD 12.89/kW, and Capacity Factor of 17%.

Using these parameters, the CRF is calculated as 0.0493, leading to an estimated CoC of 1.67% (2021), which escalates to 1.88% in 2024. This CoC, significantly lower than the current WACC of 8.52%, substantially enhances the project's economic feasibility.

When applied to the "With BESS" scenario, the reduced CoC transforms the project's financial indicators, turning the NPV from a negative value to a surplus of USD 4.31 million, with a PI of 1.11 and an IRR of 5.89%. However, the trade-off for this improved feasibility is an extended payback period of 13 years, as illustrated in Table 7.

Table 7 Economic Analysis Summary

Economic Indicators	Scenario 1.a.	Scenario 1.b.	Scenario 2.a.	Scenario 2.a.	Scenario 2.b.	Scenario 2.b.	Scenario 2.c.
	Without BESS	**Without BESS & Trans. Line ≤ 4km**	**With BESS**	**With BESS & Tariff +39.2%**	**With BESS & Carbon Tax**	**With BESS, Carbon Tax & Tariff +36.15%**	**With BESS & Competitive Auction**
Expected Rate of Return	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%	15.00%
WACC	8.52%	8.52%	8.52%	8.52%	8.52%	8.52%	1.88%
NPV	2,809,173.76	1,947,950.90	-1,646,346.18	3,895,631.52	-1,221,784.12	3,889,417.91	4,314,174.61
PI	1.39	0.84	-0.42	1.00	-0.31	1.00	1.11
Payback Period	4 yrs 10 mo	4 yrs 10 mo	NA	6 yrs 8 mo	NA	6 yrs 10 mo	13 yrs 11 mo
IRR	21.30%	16.12%	5.89%	14.79%	6.60%	14.74%	5.89%
Margin = IRR - WACC	12.78%	7.60%	-2.63%	6.27%	-1.92%	6.22%	4.01%
Project Feasibility	YES	YES	NO	YES	NO	YES	YES

Remarks: Trans means Transmission, yrs means years, mo means months, & means and.

These findings are consistent with global trends, such as Brazil's hybrid descending clock auction, which achieved a 17% reduction in LCOE (Sirin et al., 2021). Competitive auctions have proven effective in reducing financing costs, making them a viable mechanism for enhancing the economic performance of renewable energy projects.

5. CONCLUSION

This study identified the optimal configuration for a 10 MW grid-connected solar PV system at the selected location, utilizing PV modules of 425 Wp paired with a 1-string inverter (8 MW, 750–1250 VDC). Optionally, the system can be enhanced with a Li-Ion BESS of 22.5 MWh (600 V) to minimize grid dependency. The design fulfils the capacity commitment set in the PPA, determined as 70% of the projected PV output for the location.

The technical and economic analysis reveals that solar PV systems without BESS are both feasible and financially viable under existing tariff conditions. However, careful consideration of plant proximity to the off-taker is critical to avoid high transmission costs, which can erode project economics.

For solar PV systems with BESS, achieving economic feasibility requires a combination of targeted interventions. First, adjustments to the carbon tax are critical, as the current rate of USD 3.64/ton CO2e is insufficient to significantly improve project economics. A substantial increase to at least USD 47.4/ton CO2e, or alternatively, its combination with a tariff adjustment of 36.15%, would create the necessary financial incentives to make such projects viable.

Additionally, tailored tariff and incentive programs are essential for addressing the high upfront costs of energy storage. These programs should ensure that projects with BESS receive adequate compensation for their added value in enhancing grid reliability and reducing dependency on conventional energy sources. Finally, implementing competitive auction schemes can further enhance feasibility by lowering the LCOE and CoC. International examples have demonstrated that auctions not only drive cost efficiencies but also foster innovation and competition among developers. Adopting such a model in Indonesia could unlock the economic potential of utility-scale solar PV systems with BESS, thereby accelerating the country's transition to renewable energy.

This study emphasizes the importance of a multi-pronged policy approach to accelerate solar PV adoption in Indonesia. Strategic measures such as competitive auctions, progressive carbon tax policies, and well-structured tariff adjustments can drive significant progress toward achieving the country's renewable energy targets and decarbonization goals. These findings offer actionable insights for stakeholders, including policymakers, project developers, and investors, to scale renewable energy deployment effectively and sustainably.

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LAUDATE DEUM: A FRAMEWORK FOR ENVIRONMENTAL STEWARDSHIP AND SOCIAL JUSTICE IN THE PHILIPPINES AND SOUTHEAST ASIA

Antonio Levy S. Ingles, Jr.[1*]

[1]*De La Salle-College of Saint Benilde, 2544 Taft Avenue, Malate, Manila, 1004, Philippines*

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ABSTRACT

This study explores the intersection of environmental initiatives and social justice movements in the Philippines, a nation rich in biodiversity but acutely vulnerable to climate change and ecological degradation. Using *Laudate Deum* as a guiding framework, the research examines how the principles of Immediate Action, Collective Responsibility, and Social Justice can inform collaborative strategies to address these challenges. Through an analysis of case studies, this paper highlights the socio-economic impacts of environmental crises, such as deforestation and pollution, and evaluates initiatives like mangrove reforestation and community-based waste management for their ecological and social benefits. The findings reveal that integrating *Laudate Deum* principles advances synergies between environmental restoration and social equity, emphasizing the need for participatory approaches that empower marginalized communities. This study concludes with actionable recommendations, including strengthening partnerships across sectors, aligning environmental policies with socio-economic needs, and enhancing monitoring frameworks to ensure long-term sustainability. By linking ecological stewardship with social justice, *Laudate Deum* provides a unifying framework for achieving a just and sustainable future.

Keywords: *Laudate Deum*; Environmental stewardship; Social justice; Grassroots movements; Faith-based advocacy; Catholic teachings; Southeast Asia; Philippines; Climate action; Collective responsibility; Policy impact; Sustainability

1. INTRODUCTION

Pope Francis' encyclical *Laudate Si'*, released on May 24, 2015, significantly shaped global dialogue on climate change by framing it as both an environmental crisis and a pressing social justice concern. The encyclical called attention to the role of developed nations, whose historical exploitation of natural resources has significantly contributed to climate change. It criticized policies that hinder the progress of less-developed countries as inherently unjust. Central to Francis' message is the concept of integral ecology, which connects environmental care with human dignity and sustainable development, advocating for a comprehensive approach where addressing climate change is also an act of solidarity with the poor and vulnerable (Burke, 2018; Rajamani, 2015).

Laudate Si' emphasizes the moral imperative to combat climate change. A study by Buckley (2020) has shown its influence in shaping public awareness of the climate issues and encouraging collective action. Furthermore, the Paris Climate Agreement of December 12, 2015, introduced a more balanced approach to the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDRRC).

*Corresponding author's email: antoniolevy.inglesjr@benilde.edu.ph
DOI: 10.7454/jid.v7.i3.1173

This agreement prioritizes equity by enabling developing countries to pursue economic growth while assigning greater accountability for emissions reductions and climate financing to developed countries (Burke, 2018).

Laudate Si' marked a pivotal moment in the Catholic Church's engagement with environmental issues (Pope Francis, 2015), which highlights the urgent need for ecological transformation and active community participation as essential strategies for addressing climate change and promoting social equity (Beltran, 2019). While *Laudate Si'* laid the groundwork by framing climate change as a moral crisis, *Laudate Deum* builds on this vision by urging concrete, time-sensitive actions to mitigate the worsening climate crisis. Expanding upon these foundational principles, Pope Francis issued the apostolic exhortation *Laudate Deum* on October 4, 2023, which heightens the urgency of addressing the climate crisis and its profound impacts on human dignity. The Philippines, a country uniquely vulnerable to typhoons, flooding, and resource depletion, provides a critical case for examining the principles of Immediate Action and Social Justice outlined in *Laudate Deum*.

In *Laudate Deum*, Pope Francis states, "With the passage of time, I have realized that our responses have not been adequate, while the world in which we live is collapsing and may be nearing the breaking point. In addition to this possibility, it is indubitable that the impact of climate change will increasingly prejudice the lives and families of many persons. We will feel its effects in the areas of healthcare, sources of employment, access to resources, housing, forced migrations, etc." (Knox, 2023).

Laudate Deum carries relevance in the Philippines and Southeast Asia context, as the region faces significant environmental degradation and socio-economic disparities. This interdisciplinary analysis integrates theological principles, environmental science, and socio-economic frameworks to offer a holistic understanding of these interconnected challenges. Therefore, this study aims to investigate the intersection of environmental initiatives and social justice movements in the Philippines, using *Laudate Deum* as a guiding framework. Specifically, it seeks to evaluate how the principles of Immediate Action, Collective Responsibility, and Social Justice can inform and strengthen collaborative responses to these pressing challenges. The research explores key questions: How can environmental efforts address the socio-economic needs of vulnerable populations? What role can faith-based advocacy and social justice movements play in fostering more equitable and sustainable practices?

By analyzing case studies of local initiatives, such as mangrove reforestation and community-based waste management, alongside social justice campaigns for Indigenous land rights and urban housing reform, this paper examines how participatory approaches can drive both ecological restoration and socio-economic resilience. The findings demonstrate that aligning the principles of *Laudate Deum* with practical actions can bridge gaps between policy, community engagement, and sustainability, offering a comprehensive framework for addressing these interconnected issues.

2. LITERATURE STUDY

While extensive research has explored the role of religion in promoting environmental stewardship, only a limited number of studies have examined the application of *Laudato Si'* and *Laudate Deum* within the Southeast Asian context. Much of the existing literature focuses on isolated initiatives, often overlooking their broader socio-political implications or how these faith-based movements address social justice and climate inequality. This paper seeks to address this gap by examining how faith-based movements inspired by these documents contribute to addressing environmental challenges and advancing social justice in the region.

Pope Francis' 2015 encyclical, *Laudato Si'*, introduced the concept of integral ecology, which emphasizes the interconnectedness of environmental, social, and economic systems. While many studies have analyzed its influence on global environmental discourse and its integration into Catholic social teaching, fewer have focused on its direct impacts in Southeast Asia. This region, characterized by high vulnerability to climate change, provides a critical case for exploring how *Laudato Si'* has shaped grassroots movements and policy reforms. For instance, research by Beltran (2019) highlights the importance of faith-based advocacy in addressing climate-related disasters, particularly among marginalized communities.

Expanding upon these concepts, Pope Francis released *Laudate Deum* in 2023, which deepens the call for immediate and collective action to address the worsening climate crisis while emphasizing environmental stewardship and social justice (World Bank, 2019). Although global in scope, its relevance to Southeast Asia lies in its emphasis on climate resilience, sustainable development, and protection of vulnerable populations. However, studies specifically evaluating the reception and application of *Laudate Deum* in this region remain limited.

The Philippines, a biodiversity hotspot, exemplifies the environmental and social challenges addressed in *Laudato Si'* and *Laudate Deum*. Numerous studies, such as those by the United Nations Framework Convention on Climate Change (2016), the Department of Environment and Natural Resources (2022), and United Nations Development Programme (2020), underline the country's exposure to typhoons, rising sea levels, deforestation, and pollution. However, few works critically assess how faith-based initiatives, inspired by these papal documents, have mobilized communities to address these threats or influenced public policy. Moreover, Indigenous communities and the urban poor remain disproportionately affected by environmental degradation, as seen in the case of Typhoon Haiyan in 2013, which devastated the livelihoods of millions and exposed systemic inequities in disaster response and resource distribution (CARE, 2014). These storms are projected to increase in intensity and frequency due to climate change (Department of Environment and Natural Resources, Philippines, 2022).

Across Southeast Asia, issues such as deforestation, pollution, and marine ecosystem degradation persist, with significant implications for socio-economic stability. Studies by the World Wildlife Fund for Nature (2024) document the widespread encroachment of industrial activities on Indigenous territories in Borneo and the threats posed by overfishing to coastal communities. Despite these challenges, the role of religion and faith-based organizations in addressing these issues has received less scholarly attention compared to other socio-economic or political drivers. This paper contributes to filling this gap by exploring how Catholic social teachings, as articulated in *Laudato Si'* and *Laudate Deum*, inform community-led environmental efforts and regional collaborations.

Addressing these interlinked challenges requires a collaborative regional approach. Several studies (Fauzi, 2024; Valenzuela, Esteban, & Onuki, 2023) have emphasized the need for harmonized policies and shared knowledge to address transboundary issues such as air and water pollution, climate change, and deforestation. However, further research is needed to evaluate how faith-inspired frameworks, such as integral ecology, can complement secular environmental strategies. This study extends the existing literature by analyzing case studies that demonstrate the integration of Catholic social teaching into practical solutions for Southeast Asia's most pressing environmental and social challenges.

3. METHOD

This study adopted a descriptive qualitative case study design to examine the interplay between environmental initiatives and social justice movements shaped by *Laudate Deum*. A structured

framework guided the research, ensuring alignment with its objectives to inform policy and promote community-based action in environmental and social justice matters across the Philippines and Southeast Asia. Table 1 outlines the research process, detailing each stage from setting objectives to data analysis and formulating recommendations.

The study was guided by Pope Francis' call for the transformation of fundamental values, reflecting the Christian concept of metanoia, which "transfigures our goals and sheds light on our relationship to others and with creation as a whole" (Howles, 2023).

Table 1 Descriptive Qualitative Case Study Design Workflow

Step	Description
Identify Research Objectives	Define the primary research goals, specifically exploring the influence of *Laudate Deum* on environmental stewardship and social justice in the Philippines and Southeast Asia.
Select Case Studies	Conduct a literature review to identify and select relevant case studies. The selection criteria should align with *Laudate Deum*'s themes, particularly initiatives involving environmental sustainability, social justice, and advocacy for marginalized communities.
Conduct Data Collection	Gather qualitative data through document analysis of reports, policy papers, governmental publications, and case study documentation. This process is integrated with the literature review and targets understanding the practical applications of the identified initiatives.
Analyze Data	Apply comparative analysis techniques to evaluate the identified case studies. This involves discerning best practices, common challenges, and innovative strategies for addressing environmental and social justice issues in line with *Laudate Deum*.
Compile Findings	Synthesize the findings into a cohesive report that illustrates the impacts of *Laudate Deum* on environmental stewardship and social justice. The report should emphasize actionable insights from case studies and advocate for the replication of effective initiatives.
Make Recommendations	Formulate practical recommendations aimed at policymakers, NGOs, and faith-based advocacy, focusing on the integration of environmental ethics and social justice in future initiatives. This includes suggestions for future research and potential areas for collaboration.

The primary research objectives of this study were to explore the influence of *Laudate Deum* on environmental stewardship, social justice movements, and policy actions. This study sought to understand how *Laudate Deum* shapes sustainable environmental practices, addresses socio-economic inequities, and offers actionable insights for policymakers, NGOs, and faith-based advocacy groups.

The study employed case studies to analyze various environmental initiatives and social justice movements. Case studies were identified through a literature review using specific criteria, including relevance to *Laudate Deum*'s principles of Immediate Action, Collective Responsibility, and Social Justice. Data collection involved qualitative analysis of reports, policy documents, and case studies, supplemented by a comprehensive review of relevant literature to explore the practical applications of *Laudate Deum* principles.

To ensure thorough analysis, the study applied the *Laudate Deum* framework (Table 2), which outlines three central principles: Immediate Action, Collective Responsibility, and Social Justice. These principles guided the evaluation of each initiative's effectiveness in addressing environmental challenges and advancing social equity.

Table 2 Representation of the *Laudate Deum* Framework Visualization

*Principle / **Process or Outcome	Description	Action Steps
*Immediate Action	Urgent need for immediate and decisive action to address environmental crises.	Implement rapid response strategies; Support quick remediation policies.
*Collective Responsibility	Shared duty to protect and preserve the planet for current and future generations.	Foster cross-community and international collaboration; Engage in global agreements.
*Social Justice	Moral obligation to ensure fairness and equity, especially for the vulnerable.	Advocate for policies addressing marginalized groups; Promote equitable resource access.
**Sustainable Practices	Long-term actions integrating the above principles for ongoing sustainability.	Develop and adopt sustainable practices; Monitor and evaluate effectiveness.

To assess the effectiveness of initiatives, the study used the criteria summarized in Table 3. This structured method draws on *Laudate Deum*'s principles—Immediate Action, Collective Responsibility, Social Justice, and Sustainable Practices—to evaluate environmental and social justice initiatives effectively. This organized approach enables the evaluation of effectiveness in addressing environmental challenges while supporting social justice. Identifying best practices and encouraging collaboration among stakeholders provides a practical tool for guiding policy development and advancing equitable environmental management (GRI, 2024).

Table 3 Criteria for Comparison

Criteria	Description
Immediate Action	Evaluates the urgency and responsiveness of environmental initiatives in addressing ecological crises.
Timeliness	Assesses how quickly initiatives were implemented in reaction to environmental issues, emphasizing the need for rapid responses.
Effectiveness	Measures the tangible impacts these initiatives have made on environmental degradation and crisis mitigation.
Collective Responsibility	Examines the shared obligations among stakeholders to work together for environmental protection.
Community Engagement	Evaluates how well initiatives fostered participation and input from various stakeholders, including local communities and NGOs.
Collaboration	Looks at the extent of partnerships formed across borders or organizations and the results of these collaborations.
Social Justice	Analyzes the integration of fairness and equity in environmental initiatives, particularly regarding marginalized communities.
Equity and Inclusion	Assesses whether initiatives prioritize the needs and rights of vulnerable populations, ensuring their involvement in decision-making.
Access to Resources	Evaluates how initiatives promote fair access to environmental resources and benefits for disadvantaged groups.
Sustainable Practices	Reviews strategies implemented to ensure the long-term viability of environmental and social benefits from the initiatives.
Long-Term Sustainability	Considers the ongoing actions taken to maintain environmental health and social equity beyond initial implementation.

The Immediate Action principle emphasizes the pressing need to confront environmental crises such as deforestation, pollution, and climate change. Rapid implementation of policies and initiatives to combat environmental degradation is essential, particularly in Southeast Asia, where nations like Indonesia and Malaysia grapple with significant challenges. Immediate Action is pivotal in curbing deforestation, reducing pollution, and ensuring timely interventions to mitigate ecological harm.

This principle is evaluated by assessing how quickly initiatives respond to ecological crises, such as implementing pollution control measures and disaster preparedness programs. The timeliness of project mobilization is critical, encompassing both emergency responses and long-term planning. Effectiveness is further measured through tangible outcomes, including pollution reduction, biodiversity restoration, and strengthening community resilience. For example, case studies from the region showcase how Immediate Action programs have achieved measurable ecological and social benefits.

The Collective Responsibility principle underscores the shared duty of individuals, communities, governments, and international organizations to safeguard the environment for current and future generations. In Southeast Asia, this principle highlights the critical importance of cross-border collaboration and regional partnerships in addressing shared environmental challenges. One notable example is the ASEAN Agreement on Transboundary Haze Pollution, which seeks to reduce air pollution caused by land and forest fires. This agreement exemplifies the necessity of coordinated efforts among stakeholders across all levels, emphasizing resource sharing and capacity development to achieve significant progress (The Association of Southeast Asian Nations, 2021). Community engagement, such as involving local populations in decision-making processes, enhances long-term commitment to environmental conservation and promotes ownership of initiatives.

The principle of Social Justice integrates environmental stewardship with fairness and equity, ensuring that marginalized communities are not excluded from decision-making processes and resource distribution. In Southeast Asia, Indigenous peoples and rural communities disproportionately bear the brunt of environmental degradation, including deforestation, pollution, and climate-induced displacement. Social Justice ensures their participation in decision-making, equitable access to resources, and the protection of ancestral lands.

For instance, the Philippines' 1997 Indigenous Peoples' Rights Act (IPRA) marked a significant milestone in promoting equity by recognizing Indigenous tribes' ancestral domains (Lilley, 2022). However, challenges persist as the growing global demand for natural resources threatens Indigenous lands. Similarly, in Cambodia, a legal framework recognizes Indigenous land rights and allows collective management of territories. Despite this progress, implementation gaps—such as delays in granting formal land titles—highlight the ongoing need for accountability and monitoring (de Lange, Raj, & Mane, 2023). Case studies reveal how prioritizing equity and inclusion in initiatives empowers disadvantaged populations and demonstrates the connection between inclusive practices and improved outcomes.

Access to Resources, a key aspect of Social Justice, evaluates how initiatives ensure the fair distribution of environmental benefits, especially for historically disadvantaged groups. Programs addressing resource inequalities and promoting conservation practices are emphasized for their role in empowering marginalized communities.

Sustainable Practices function as both a means and an end within the *Laudate Deum* framework, integrating Immediate Action, Collective Responsibility, and Social Justice into strategies that foster long-term sustainability. These practices are evaluated through the adoption of environmentally friendly technologies, community-driven conservation projects, and frameworks that maintain ecological health over time. Southeast Asia presents significant

examples: Thailand's community-based marine resource management safeguards biodiversity, while Malaysia's solar energy expansion reduces carbon emissions and enhances social welfare (CARE, 2014; World Wildlife Fund for Nature, 2024).

The concept of long-term sustainability examines how well planning and policies embed sustainability principles into their design to preserve environmental health. For example, projects in Thailand demonstrate how ongoing assessments and adaptive planning have strengthened marine ecosystems and benefited coastal communities. Monitoring and Evaluation frameworks are critical for ensuring the success of such initiatives, as they allow programs to adapt to evolving circumstances, address challenges, and refine approaches over time.

The *Laudate Deum* framework comprehensively addresses the interconnected environmental and social challenges of Southeast Asia, offering actionable principles for regional and national policymakers. Immediate Action and Collaborative Responsibility are essential to addressing deforestation in Indonesia, overfishing in Thailand, and urban pollution across the region. Social Justice plays a central role in empowering Indigenous and marginalized populations, ensuring their inclusion in decisions that shape their lives and livelihoods. By integrating urgency, collaboration, and equity, the framework serves as a practical guide for advancing environmental stewardship and social equity in a sustainable and inclusive manner.

4. RESULTS AND DISCUSSION

This section explores the interconnected challenges of environmental degradation, socio-economic impacts, and social justice movements in the Philippines. Using the principles of *Laudate Deum* as a guiding framework, the discussion highlights how environmental initiatives and social justice movements address these issues, focusing on the Philippines, as its geographical vulnerability to climate change, coupled with its heavy reliance on agriculture, emphasize the urgent need for comprehensive disaster risk reduction and adaptation strategies.

Environmental degradation poses significant threats to biodiversity and the depletion of natural resources, underscoring the urgent need for conservation and sustainable management practices. Beyond ecological concerns, this degradation imposes wide-ranging socio-economic consequences, including heightened health risks from pollution-related diseases and respiratory issues, disruptions to livelihoods as resource depletion undermines income and employment in agriculture, fisheries, and forestry, and escalating economic costs for disaster response and recovery. These impacts disproportionately affect rural communities that rely heavily on natural resources for their survival, further highlighting the critical intersection of environmental sustainability and socio-economic resilience.

Several successful local initiatives have demonstrated effective responses to pressing environmental challenges, showcasing the power of community-driven efforts. Mangrove reforestation projects, for instance, play a critical role in restoring coastal ecosystems, protecting communities from storm surges, enhancing biodiversity, and creating livelihood opportunities for local residents. Similarly, community-based waste management programs empower individuals to address pollution through effective waste management and recycling practices, leading to improved public health outcomes and reduced environmental degradation. These localized initiatives highlight how targeted, participatory approaches can simultaneously advance environmental restoration and bolster socio-economic resilience.

Social justice movements in the Philippines are pivotal in tackling inequities intensified by environmental degradation, demonstrating the transformative power of community mobilization. Efforts advocating for farmers' rights focus on securing land tenure and promoting sustainable farming practices, ensuring agricultural livelihoods are protected. Campaigns for Indigenous

peoples' rights aim to safeguard ancestral lands from deforestation and mining activities, preserving cultural heritage and natural ecosystems. Meanwhile, urban poor housing rights movements strive to provide safe and affordable housing, particularly in areas prone to environmental hazards. Collectively, these movements showcase how grassroots advocacy can drive policy changes and foster social equity in the face of environmental challenges.

The teachings of *Laudate Deum* have profoundly shaped environmental policy reforms and civil society engagement in the Philippines, fostering a more integrated and ethical approach to addressing ecological challenges. This document has encouraged businesses to embrace corporate social responsibility by adopting sustainable practices and prioritizing environmental health. It has also promoted a holistic perspective, highlighting the interconnectedness of environmental health, socio-economic stability, and social equity. Furthermore, *Laudate Deum* has strengthened stakeholder collaboration, fostering partnerships between government agencies, NGOs, faith-based organizations, and local communities to tackle shared challenges. By emphasizing the moral and ethical dimensions of environmental stewardship, *Laudate Deum* has catalyzed a transformative shift toward integrated and collaborative solutions for complex environmental and social issues.

This comprehensive overview highlights the critical need for integrated strategies to address the intricate interplay of environmental, socio-economic, and social justice issues. Recognizing the interconnectedness of these challenges enables stakeholders to develop sustainable solutions that tackle the root causes of environmental degradation, enhance community resilience through inclusive and participatory approaches, and promote equity by ensuring that marginalized groups benefit from environmental and socio-economic initiatives. These interconnected efforts pave the way for more holistic and impactful responses to the pressing challenges of our time.

Table 4 Overview of Environmental Issues in the Philippines

Environmental Issue	Description
Climate Change	Increasing temperatures, changing rainfall patterns, and rising sea levels leading to more frequent and severe weather events such as typhoons, floods, and droughts. "We realize that these are extraordinary times, necessitating extraordinary action from us. Nature is sending us a message that we need to take better care of our environment. It is time to stop the abuse of nature. It is time to build a better normal. It's time to conserve and protect our nature," (Climate Change Commission, 2024a).
Deforestation	Rapid loss of forest covers due to logging, agricultural expansion, and infrastructure development, resulting in habitat destruction, loss of biodiversity, and soil erosion. Global Forest Watch (2024) reports that from 2002 to 2023, the Philippines lost 190 kha of humid primary forest, accounting for 13% of its total tree cover loss during this period.
Pollution	Contamination of air, water, and soil due to industrial activities, vehicle emissions, improper waste disposal, and agricultural runoff, leading to health hazards and ecosystem degradation. Untreated household sewage and industrial and agricultural waste are the primary contributors to the pollution of almost half or 180 of the nation's 421 rivers (Filipenco, 2024).

Through collaborative efforts, it is possible to address these multidimensional challenges and build a more just and sustainable future for all. By leveraging the principles outlined in *Laudate Deum*, stakeholders can create a unified framework that prioritizes environmental health, socio-economic stability, and social equity, ultimately fostering a resilient and inclusive society.

Table 4 offers a concise overview of the primary environmental challenges confronting the Philippines. It identifies three major issues: climate change, deforestation, and pollution. For each issue, the table provides a brief description, detailing the main causes and their associated consequences.

4.1 Environmental Initiatives in the Philippines and Southeast Asia

Environmental initiatives in the Philippines and Southeast Asia are vital in addressing the region's vulnerability to climate change. Local community efforts, sustainable agricultural practices, and supportive policies contribute to mitigating the risks posed by extreme weather events and environmental degradation. This section examines these initiatives, linking them to key vulnerability factors and emphasizing their importance in fostering resilience.

Many environmental initiatives emphasize grassroots mobilization, empowering local communities to actively engage in conservation efforts and contribute to environmental sustainability. Notable examples include mangrove reforestation projects, which protect coastal areas from storm surges and erosion while enhancing biodiversity, and coastal clean-up campaigns organized by local NGOs, which address pollution and encourage community participation in environmental restoration. By fostering local involvement, these initiatives cultivate a strong sense of ownership and long-term commitment among community members, ensuring the sustainability and impact of conservation efforts over time.

The growing emphasis on sustainable agricultural practices reflects an increasing awareness of the need to balance economic development with environmental sustainability. Examples of such practices include organic farming, which minimizes the use of chemical fertilizers and pesticides, thereby promoting soil health and reducing water pollution, and agroforestry, which integrates agriculture with tree planting to enhance land productivity, support biodiversity, and mitigate climate risks. Case studies of successful implementations highlight the positive outcomes of these approaches, including improved livelihoods, enhanced food security, and significant contributions to environmental preservation, demonstrating their potential as effective solutions for sustainable development.

Governmental frameworks are pivotal in supporting environmental initiatives, providing the regulatory backbone for addressing ecological challenges. Notable examples include the Philippine Clean Air Act, which seeks to reduce air pollution through stricter regulations on emissions and waste management, and the ASEAN Agreement on Transboundary Haze Pollution, which emphasizes regional collaboration and shared responsibility to mitigate air pollution caused by forest and land fires. While these policies represent significant progress, enforcement and compliance remain critical challenges. Strengthening these frameworks through enhanced monitoring, increased funding, and active community participation is essential to ensure their effectiveness and long-term impact.

The factors contributing to the Philippines' vulnerability to climate change and extreme weather events are multifaceted, as outlined in Table 5. Its geographic location along the typhoon belt and the Pacific Ring of Fire subjects the country to frequent tropical storms, earthquakes, and volcanic activity. Coastal communities, with their extensive coastlines, are particularly at risk from rising sea levels, storm surges, and coastal erosion. Additionally, the heavy reliance on climate-sensitive agricultural activities leaves a significant portion of the population vulnerable to the impacts of extreme weather. Limited resources, including inadequate infrastructure, insufficient funding, and weak disaster preparedness, further exacerbate the country’s ability to respond effectively to climate-related challenges. According to the Asian Development Bank (2021), an estimated 60% of the Philippines’ land area is exposed to natural hazards, with over 70,000 lives lost to disasters

in recent decades. These interconnected factors highlight the country's susceptibility to climate risks and emphasize the pressing need for comprehensive and proactive adaptation strategies.

Table 5 Vulnerability to Climate Change and Extreme Weather Events

Vulnerability Factor	Description
Geographic Location	The Philippines is situated in the Pacific Ring of Fire and the typhoon belt, making it prone to earthquakes and typhoons.
Coastal Communities	Vulnerable coastal communities are at risk of flooding, storm surges, and sea-level rise due to their proximity to the ocean.
Agricultural Dependence	The country's reliance on agriculture makes it susceptible to climate variability, affecting crop yields and food security.

Environmental degradation in the Philippines significantly affects both ecosystems and human communities. The loss of biodiversity, the decline of ecosystem services, and increased exposure to natural disasters compound socio-economic vulnerabilities, particularly for marginalized groups. These issues are closely linked to social justice concerns, as environmental degradation disproportionately impacts impoverished and disenfranchised populations.

Environmental initiatives in the Philippines and Southeast Asia prioritize grassroots engagement, enabling local communities to participate actively in conservation efforts. Programs such as mangrove reforestation protect coastal areas from storm surges, improve biodiversity, and deliver essential ecosystem services. In contrast, coastal clean-up drives tackle pollution and encourage community involvement in environmental restoration. Supported by local NGOs, these efforts are often paired with sustainable agricultural practices, such as agroforestry and organic farming, which integrate economic development with environmental conservation. These initiatives collectively strengthen resilience in vulnerable communities, promoting ecological sustainability and socio-economic stability.

Environmental degradation in the Philippines significantly affects biodiversity and natural resources, as shown in Table 6. The country faces widespread biodiversity loss driven by deforestation and habitat destruction, with forests, wetlands, and other critical ecosystems increasingly threatened by agricultural expansion, logging, and urban development. Pollution, overexploitation, and other human activities have further degraded ecosystems, impairing their capacity to deliver essential services such as water purification, carbon storage, and climate regulation. Moreover, the Philippines' extensive coral reef systems, crucial for marine biodiversity and fisheries, are severely impacted by coral bleaching, overfishing, and coastal development.

Recognized as one of the world's 18 mega-biodiverse countries, the Philippines plays a vital role in global biodiversity conservation. However, according to the Climate Change Commission (2024), the continued degradation of these ecosystems not only threatens the country's natural heritage but also jeopardizes the livelihoods of millions of Filipinos who depend on these resources for sustenance, income, and protection from natural disasters.

The socio-economic consequences of environmental degradation in the Philippines are profound, affecting health, livelihoods, and the economy, as outlined in Table 7. Health risks are a major concern, with air and water pollution contributing to rising public health challenges. Air pollution, identified as the third leading cause of death and disability from non-communicable diseases, significantly increases the prevalence of respiratory illnesses (Centre for Research on Energy and Clean Air, 2024).

Table 6 Impact on Biodiversity and natural Resources

Impact	Description
Loss of Biodiversity	Deforestation, habitat destruction, and pollution contribute to the loss of plant and animal species in the Philippines. The Philippines is recognized as one of the 18 mega-biodiverse countries globally, hosting 70 to 80 percent of the world's plant and animal species (Climate Change Commission, 2024).
Degradation of Ecosystems	Environmental degradation affects the functioning of ecosystems, reducing their resilience and ability to provide services.
Threat to Coral Reefs	Pollution, overfishing, and climate change pose significant threats to coral reefs, affecting marine biodiversity and fisheries.

Similarly, contaminated water sources exacerbate waterborne diseases such as diarrhea and cholera, highlighting the urgent need to strengthen the health workforce and enhance public health preparedness, particularly in the post-pandemic era.

Table 7 Socio-economic Implications of Environmental Degradation

Socio-economic Aspect	Description
Health Risks	Environmental pollution contributes to respiratory diseases, waterborne illnesses, and other health problems in communities.
Livelihood Disruption	Loss of natural resources and agricultural productivity due to environmental degradation impacts the livelihoods of rural communities.
Economic Costs	The Philippines incurs economic losses from environmental disasters, including infrastructure, agriculture, and tourism damage.

Environmental degradation also disrupts rural livelihoods, especially for communities dependent on natural resources. Initiatives like the VISTA Program aim to support 350,000 small-scale farmers, focusing on women, youth, and Indigenous peoples, by enhancing value chains, promoting sustainable land use practices, and building climate resilience (IFAD, 2024). Additionally, the economic costs of disasters, including typhoons, floods, and droughts, significantly burden infrastructure, agriculture, and tourism. The Philippine Statistics Authority (2024) reported 208 extreme natural events and disasters in 2023 alone, underscoring the critical need for robust disaster preparedness and mitigation strategies to address these ongoing challenges.

The socio-political history of the Philippines and Southeast Asia, shaped by colonial rule and authoritarian regimes, has profoundly influenced the rise of social justice movements to combat systemic inequities. Among these are labor rights campaigns advocating for fair wages and safer working conditions, Indigenous rights initiatives focused on protecting ancestral lands and preserving cultural heritage, and gender equality movements working to dismantle systemic discrimination and empower women and marginalized genders. While these efforts have achieved notable progress, such as policy reforms and heightened public awareness, they continue to face entrenched structural inequalities and resistance to change, highlighting the ongoing challenges in attaining comprehensive social justice.

Youth engagement has become a key driver in advancing social justice, with young activists increasingly utilizing digital platforms and social media to broaden their reach. These tools enable the organization of grassroots movements, providing a platform for marginalized voices and advocating for interconnected issues such as poverty, land rights, and environmental degradation.

Through technology, young leaders raise awareness, build support, and mobilize collective action, demonstrating the potential of digital tools to drive equitable and sustainable change.

Social justice movements and environmental initiatives aim to address systemic inequities and ecological challenges. This overlap is particularly evident in efforts to empower marginalized communities to participate actively in conservation and climate resilience programs, while advocating for equitable access to natural resources and sustainable livelihoods. By integrating social equity into environmental policies, these efforts ensure that vulnerable populations not only contribute to conservation but also benefit from it, promoting a more inclusive and sustainable approach to addressing global challenges.

Tackling the interconnected issues of environmental degradation and socio-economic inequality requires a holistic approach to activism. By addressing overlapping concerns such as poverty, land rights, public health, and biodiversity loss, stakeholders can achieve social and environmental justice within a unified framework.

Table 8 showcases case studies of successful environmental initiatives across different regions of the Philippines, detailing their goals, approaches, and outcomes. One notable project is the mangrove reforestation effort in Palawan, aimed at restoring mangrove ecosystems to shield coastal communities from storm surges and improve biodiversity. In Davao City, community-based waste management programs tackle solid waste issues through innovative recycling methods and waste-to-energy projects. Additionally, renewable energy initiatives in Batangas focus on solar power development, supported by national policies that promote clean and sustainable energy practices. These case studies highlight the effectiveness of localized strategies in addressing environmental challenges while contributing to the overarching goals of sustainable development.

Table 8 Case Studies of Environmental Initiatives in the Philippines

Case Study	Description
Mangrove Reforestation in Palawan	This case study describes a successful mangrove reforestation project in Palawan, Philippines. It outlines the goals, methods, and outcomes of the initiative, including benefits for biodiversity conservation and coastal protection.
Community-Based Waste Management in Davao City	This case study examines a community-based waste management program implemented in Davao City. It discusses the strategies employed to reduce waste generation, promote recycling, and engage local communities in sustainable practices.
Renewable Energy Project in Batangas	This case study highlights a renewable energy project in Batangas province, focusing on the installation of solar panels and wind turbines. It explores the project's contribution to reducing carbon emissions and enhancing energy security in the region.

Mangrove ecosystems in Palawan have been recognized for their ecological importance since 1981 when the province was designated as a mangrove swamp forest reserve under a presidential decree. Despite this recognition, preservation efforts have been insufficient, with continued mangrove loss attributed to government neglect (Reyes Jr., 2024). Mangroves play a vital role in protecting coastal communities from natural disasters such as typhoons and supporting biodiversity, as emphasized by Dr. Jurgenne Primavera. Local communities have undertaken several initiatives to combat deforestation and restore mangrove ecosystems. Earth Day planting events, organized to raise awareness about environmental conservation, have been effective, as reported by Marilou Manlavi, a municipal environment officer (Reyes Jr., 2024). In Malampaya

Sound, village-led reforestation efforts initiated in 2017 have significantly increased mangrove cover, directly benefiting local fishers like Panchito, who rely on healthy mangroves for their livelihoods (Fabro, 2022). These community-driven efforts highlight the importance of local engagement in mangrove conservation.

Solid waste management remains a significant challenge in Davao City, where the New Carmen Sanitary Landfill receives between 500 and 600 tons of waste daily. Initially designed to operate for 8 to 10 years, the landfill's lifespan has been curtailed due to rising waste volumes and reduced waste collection frequency. Collection has decreased from four times to twice weekly, exacerbating the strain on the city's waste management systems as waste production increases. Despite these challenges, opportunities for improvement exist. Recycling programs supported by registered recycling companies offer the potential to enhance waste segregation and increase recycling rates (Japan International Cooperation Agency, 2016). Additionally, Davao's waste has sufficient calorific value for energy recovery, presenting opportunities for waste-to-energy solutions, particularly if high-calorific waste collection improves. Japanese waste-to-energy technology could be instrumental in addressing these issues and advancing sustainable waste management in the city (Japan International Cooperation Agency, 2016).

Batangas is emerging as a leader in renewable energy, particularly in solar power, driven by the Renewable Energy Act of 2008, which offers incentives such as feed-in tariffs and tax exemptions. These measures align with national goals to reduce dependence on fossil fuels and promote cleaner, renewable energy sources. The development of solar energy systems in Batangas supports the transition to a sustainable future, showcasing the province's commitment to advancing renewable energy initiatives (Batangas Solar Energy Systems, 2024). These regional efforts exemplify the Philippines' multifaceted strategies to address environmental challenges by integrating ecosystem conservation into a holistic approach to sustainability.

Table 9 highlights prominent success stories of social justice movements in the Philippines that focus on reducing inequality and supporting marginalized groups. Key examples include farmers' rights advocacy in Negros Occidental, which enables farmers to secure land ownership and adopt modern agricultural techniques; efforts to protect Indigenous peoples' rights in Mindanao, which safeguard cultural heritage and land entitlements through the Indigenous Peoples Rights Act (IPRA); and the urban poor housing rights movement in Metro Manila, which organizes communities to achieve affordable housing and access to vital services. These initiatives demonstrate the transformative role of community mobilization, public awareness, and policy advocacy in promoting equitable development and addressing deep-rooted social injustices.

Table 9 Case Studies of Social Justice Movements in the Philippines

Movements	Description
Farmers' Rights Advocacy in Negros Occidental	This success story showcases a farmers' rights advocacy campaign in Negros Occidental. It discusses the mobilization of farmers to demand land reform, fair wages, and government support for agricultural development.
Indigenous Peoples' Rights Protection in Mindanao	This case study highlights efforts to protect the rights of indigenous peoples in Mindanao, Philippines. It examines advocacy initiatives to defend ancestral lands, cultural heritage, and self-determination of indigenous communities.
Urban Poor Housing Rights Movement in Metro Manila	This success story focuses on a housing rights movement in Metro Manila, addressing the challenges urban poor communities face. It explores advocacy efforts for affordable housing, access to basic services, and tenure security for informal settlers.

Agrarian reform initiatives in Negros Occidental have had a significant impact on local farmers, particularly through efforts to modernize agricultural practices and secure land ownership. Advocacy campaigns, such as the "Advocacy Campaign and Demonstration of Crop Establishment Technologies," have promoted the adoption of advanced farming methods with support from the Department of Agriculture and PHilMech (Provincial Government of Negros Occidental, 2024). However, the struggle for land ownership remains a critical issue, with farmers calling on the Office of the President to fulfill promises of awarding land. In Barangay Cabacungan, for example, farmers have waited decades to receive their Certificates of Land Ownership Award (CLOA), which symbolizes the culmination of their fight for land rights (Titong, 2024). These initiatives highlight the importance of sustained advocacy to empower farmers and ensure equitable access to land resources.

Housing remains a critical issue in the Philippines, impacting both urban and rural communities. The Urban Development and Housing Act (RA 7279) addresses this challenge by promoting collective action and developing settlements that integrate livelihood opportunities and basic services. Stories such as those of Delia and Hernan exemplify the transformative power of community organization in securing housing and advocating for improved living conditions. Organizations like Habitat for Humanity are vital in addressing housing poverty, having served over 106,600 families since 1988. Their efforts have improved access to healthcare, education, and livelihood training, particularly in disaster-prone areas. Through partnerships with government agencies and NGOs, Habitat for Humanity supports homebuilding, disaster recovery, and community empowerment, with notable projects assisting families affected by the 2013 Bohol earthquake and Typhoon Haiyan. These initiatives underscore the importance of collaboration, community engagement, and policy advocacy in tackling housing challenges across the country.

Significant challenges persist despite notable progress in agrarian reform, Indigenous rights, and housing development. Delays in land distribution and bureaucratic inefficiencies continue to hinder farmers' access to land ownership, undermining agrarian reform goals. Similarly, weak enforcement of the Indigenous Peoples Rights Act (IPRA) limits the realization of rights for Indigenous communities, leaving many marginalized. In the housing sector, high costs and an inadequate supply of affordable housing remain significant barriers for low-income families. These ongoing challenges highlight the urgent need for sustained advocacy, comprehensive policy reforms, and active community participation to ensure equitable access to land, housing, and essential services for all.

Table 10 highlights the transformative impact of *Laudate Deum* in influencing environmental policy-making and civil society engagement in the Philippines, even before its official release. Key areas include reforms in environmental legislation, such as strengthening the Clean Air Act of 1999 and the Ecological Solid Waste Management Act to advance sustainable practices. The table also emphasizes the role of civil society advocacy networks in bolstering grassroots initiatives and fostering collaboration among NGOs, local communities, and faith-based organizations. Furthermore, corporate social responsibility (CSR) programs have been encouraged to integrate environmental stewardship and social justice into business operations. *Laudate Deum* is shown to have validated and amplified these efforts, offering a moral framework that reinvigorated advocacy for environmental sustainability and socio-economic equity.

The principles articulated in *Laudate Deum*—Immediate Action, Collective Responsibility, and Social Justice—resonate strongly with Catholic teachings on creation care, emphasizing the sanctity of creation as a sacred trust requiring protection and framing environmental stewardship as a civic and moral obligation. These principles are reflected in Philippine legislation through key environmental laws. The Clean Air Act of 1999 Mandates Environmental Compliance

Certificates for critical projects and involves communities in air quality management plans. The Ecological Solid Waste Management Act promotes waste segregation, reuse, and recycling at the source to minimize environmental harm. Similarly, the Clean Water Act of 2004 expands environmental protection by safeguarding water resources and integrating environmental education into school curriculums (Environmental Management Bureau, 2024). These laws align *Laudate Deum*'s principles with actionable policies for environmental sustainability.

Table 10 Impact of *Laudate Deum* on Policy Making and Civil Society

Policy Impact	Description
Environmental Legislation Reform	This section highlights the pivotal role of *Laudate Deum* in reinforcing ongoing environmental stewardship and social justice initiatives led by grassroots movements in the Philippines. Even before its official publication, the principles expressed in *Laudate Deum* resonated with and strengthened policy frameworks, including the Clean Air Act and the Ecological Solid Waste Management Act, by providing a moral and ethical foundation aligned with these grassroots efforts' objectives.
Civil Society Advocacy Networks	This section emphasizes how *Laudate Deum* catalyzed collaborations among civil society advocacy networks, enhancing the principles already championed by grassroots movements. The document echoed the collective efforts of environmental NGOs and community groups, thereby strengthening their initiatives toward policy reform and sustainable development long before its official release. These collaborations helped integrate the principles expressed in *Laudate Deum* into broader environmental and social justice movements, amplifying the impact of grassroots initiatives.
Corporate Social Responsibility Initiatives	This section explores how *Laudate Deum* strengthened corporate social responsibility (CSR) initiatives in the Philippines, even before its formal introduction. The exhortation inspired businesses to adopt sustainable practices and align their operations with ethical principles reflective of grassroots movements. By embodying the values of Immediate Action, Collective Responsibility, and Social Justice, companies contributed to a broader movement for sustainability, which *Laudate Deum* recognized and validated.

The exhortation emphasizes the importance of fostering cooperation among diverse stakeholders, highlighting the transformative potential of partnerships in advancing environmental and social goals. These collaborations empower communities through initiatives such as the Mt. Makiling Community-Based Conservation Program (MCBCP) and NGO-Assisted Community-Based Mangrove Forest Management, which train community members in sustainable practices and provide alternative livelihood opportunities (Duthy & Bolo-Duthy, 2003). Additionally, grassroots organizations like Luntiang Alyansa para sa Bundok Banahaw (LABB) showcase the success of local conservation efforts, demonstrating how community-driven initiatives can contribute significantly to environmental preservation and sustainability.

Legislators like Senator Loren Legarda exemplify integrating environmental stewardship with social justice through impactful policies and initiatives. The Climate Change Act (RA 9729) mandates gender representation in the Climate Change Commission, ensuring diverse

perspectives in addressing climate challenges (Casayuran, 2023b). Additionally, the Luntiang Pilipinas Program, a national urban greening initiative launched in 1998, has planted over two million trees, fostering environmental awareness and community engagement across the country (Casayuran, 2023a). These efforts highlight the critical role of inclusive and community-driven approaches in advancing sustainability and social equity.

Legarda emphasizes the economic potential of sustainable practices, describing them as drivers of "economic opportunities in a changed world." Her efforts highlight the importance of swift adaptation to global challenges to secure a sustainable future for the Philippines.

The influence of *Laudate Deum* permeates both grassroots and policy levels, fostering a unified approach to environmental and social justice. It emphasizes integrated environmental responsibility by aligning the efforts of communities, governments, and corporations under shared sustainability goals. The exhortation promotes holistic sustainability, balancing immediate ecological needs with long-term social equity while ensuring that marginalized communities are included in decision-making. Furthermore, it inspires future advocacy by energizing local and national initiatives with moral and ethical frameworks that encourage collective action and accountability. By uniting stakeholders across various sectors, the Philippines exemplifies the vision of *Laudate Deum* through its sustained commitment to environmental stewardship and socio-economic justice.

Table 11 showcases key environmental initiatives across Southeast Asia, highlighting efforts in Indonesia, Thailand, and Malaysia. These case studies detail the organizations involved, geographical focus, and strategies employed to advance environmental sustainability. The Kalimantan Forest Conservation Program (KFCP) addresses illegal logging in Indonesia. It promotes biodiversity preservation through community engagement, although challenges remain concerning Indigenous communities' Free, Prior, and Informed Consent (FPIC) rights. In Thailand, the Environmental Justice Foundation (EJF) collaborates with the Royal Thai Government to reform the fishing industry by establishing legal and ethical fisheries management systems while advocating for environmental defenders and Indigenous communities. In Malaysia, clean energy initiatives spearheaded by the Malaysian Solar Industry Association (MSIA) and Sarawak Energy Berhad emphasize renewable energy development, with the National Energy Transition Roadmap (NETR) aiming to achieve 70% of energy from renewables by 2050. These case studies demonstrate the diverse approaches employed across the region to address environmental challenges and promote sustainable development.

The case studies highlight key environmental initiatives in Indonesia, Thailand, and Malaysia, showcasing efforts to address pressing ecological challenges through innovative strategies and community engagement. In Indonesia, the Kalimantan Forest Conservation Program (KFCP), supported by Wahana Lingkungan Hidup Indonesia (WALHI), focuses on reducing greenhouse gas emissions, combating illegal logging, and promoting sustainable forest management. Targeting 120,000 hectares across seven villages in Central Kalimantan, the program has been endorsed by the national government since 2008 (Forest Peoples Programme, 2011). However, it has faced criticism for failing to uphold Free, Prior, and Informed Consent (FPIC) rights for the Dayak people and concerns over biodiversity loss and the commodification of nature (Friends of the Earth International, 2024a). Despite these challenges, local communities, including the Dayak, hope the project will protect remaining forests and peatlands from threats such as oil palm plantations (Courtney-Mercer, 2014).

Table 11 Case Studies of Environmental Initiatives in Southeast Asia

Country	Initiative	Location	Groups	Dates	Description
Indonesia	Forest Conservation Efforts	Central Kalimantan	Walhi (Wahana Lingkungan Hidup Indonesia); Kalimantan Forest Conservation Program	Ongoing since 2016	Initiatives include the Kalimantan Forest Conservation Project led by Walhi and the alliance, focusing on reforestation, forest patrols, and community engagement to combat illegal logging and preserve biodiversity.
Thailand	Sustainable Fishing Practices	The Andaman Sea, Gulf of Thailand	The Thai Department of Fisheries; Marine Conservation Group; Thai Fisheries Association	2015 - Present	Includes the Community-Based Marine Resource Management Program and initiatives by the Thai Department of Fisheries to regulate fishing quotas, establish marine protected areas, and promote eco-friendly fishing methods.
Malaysia	Clean Energy Projects	Sabah, Penang, and Sarawak	Malaysian Solar Industry Association (MSIA); Sarawak Energy Berhad; Penang State Government	2018 - Present	Projects such as the Solar Energy Plant in Penang and the Biogas Plant in Sabah focus on expanding solar and bioenergy capacities, with support from Sarawak Energy and MSIA to reduce reliance on fossil fuels and cut emissions.

The Environmental Justice Foundation (EJF) in Thailand has been at the forefront of fisheries reform, a critical area given Thailand's status as the sixth-largest seafood exporter globally. Since 2014, EJF has collaborated with the Royal Thai Government to implement monitoring, control, and surveillance (MCS) mechanisms while advocating for environmental defenders and Indigenous communities affected by unsustainable fishing practices. These efforts have increased transparency and accountability in the fishing industry, promoting sustainable marine resource management while ensuring economic and environmental balance (EJF, 2023). Meanwhile, Malaysia is advancing its transition to renewable energy through initiatives led by the Malaysian Solar Industry Association (MSIA) and Sarawak Energy Berhad. Guided by the National Energy Transition Roadmap (NETR), which targets 70% renewable energy by 2050, projects like Sarawak Energy's hydropower initiatives now generate over 60% of the state's electricity and facilitate trading Renewable Energy Certificates (RECs) on the Bursa Carbon Exchange (Sarawak Energy, 2024). Additionally, expanding solar and bioenergy capacities underscores Malaysia's commitment to reducing reliance on fossil fuels and achieving long-term sustainability.

The case studies from Indonesia, Thailand, and Malaysia showcase a range of strategies to address environmental challenges, emphasizing the importance of community engagement, policy reform, and innovation. Initiatives such as the Kalimantan Forest Conservation Program (KFCP) and NGO-led mangrove conservation efforts demonstrate the value of involving local communities in resource management. Thailand's fisheries reform and Malaysia's National Energy Transition Roadmap (NETR) highlight the critical role of robust policies in advancing sustainability goals. Meanwhile, clean energy projects in Malaysia underscore the need for technological innovation and financial investments to transition toward sustainable practices.

However, significant challenges remain, particularly in ensuring equity and rights for marginalized groups. For example, guaranteeing Free, Prior, and Informed Consent (FPIC) for Indigenous communities in Indonesia and advocating for environmental defenders in Thailand are pressing concerns. Strengthening governance and monitoring mechanisms across all initiatives is essential to ensure accountability and long-term success. By addressing these challenges and building on the achievements of these initiatives, Southeast Asia can develop more sustainable and inclusive frameworks for environmental stewardship.

Table 12 highlights significant social justice movements across Southeast Asia, focusing on Singapore, Vietnam, and Cambodia's efforts to advocate for marginalized communities and promote equitable reforms. In Singapore, Transient Workers Count Too (TWC2) advocates for the rights of low-wage migrant workers, tackling issues such as exploitation, substandard living conditions, and the need for legal reforms. In Vietnam, the Vietnam Women's Union (VWU) works to empower women by addressing gender-based violence, increasing women's participation in social and political domains, and supporting peace and security initiatives under the National Action Plan. In Cambodia, the Cambodian League for the Promotion and Defense of Human Rights (LICADHO) focuses on land rights, combats forced evictions, and advocates for civil, political, and economic rights during key events such as World Habitat Day. These movements showcase the effectiveness of grassroots and organizational actions in mobilizing communities, raising awareness, and driving accountability to address social justice issues and foster equitable regional reforms.

Transient Workers Count Too (TWC2) plays a critical role in advocating for Singapore's low-wage migrant workers, who comprise approximately one-sixth of the population. These workers, originating primarily from India, China, Bangladesh, Indonesia, Myanmar, and the Philippines, are integral to Singapore's economy and infrastructure, contributing significantly to construction, sanitation, and caregiving. Despite their contributions, they often face severe challenges, including widespread exploitation and poor living conditions, with new cases of abuse reported daily. Public awareness of their essential roles remains limited, further exacerbating their marginalization (Transient Workers Count Too, 2024). TWC2 advocates for systemic reforms, emphasizing the importance of the In-Principle Approval (IPA) work permit issued by the Ministry of Manpower as a critical measure to authorize foreign workers in Singapore (Transient Workers Count Too, 2024). Through advocacy and support services, TWC2 underscores the urgent need for comprehensive reforms to combat exploitation and enhance the living conditions of this vital workforce.

The Vietnam Women's Union (VWU), established in 1930 by the Communist Party of Vietnam, is a cornerstone organization in the country's social justice landscape, dedicated to promoting women's rights and advancing gender equality. Its mission focuses on mobilizing women from diverse backgrounds to actively contribute to national development while advocating for the prevention of gender-based violence and enhancing women's roles in peace-building and security (Vietnam Women's Union, 2024). The VWU's National Action Plan outlines comprehensive strategies to address gender inequality and empower women, emphasizing their vital

contributions to consolidating national peace and security. By championing these causes, the VWU underscores the critical importance of gender equity in Vietnam's socio-political development.

Table 12 Case Studies of Social Justice Movements in Southeast Asia

Country	Initiative	Location	Groups	Dates	Description
Singapore	Rights of Migrant Workers	Nationwide	Transient Workers Count Too (TWC2); Singapore Migrant Workers' Centre	Ongoing since 2009	Advocacy includes campaigns for better living conditions, legal reforms for fair treatment, and support services for migrant workers, with TWC2 providing legal aid and support to improve workers' rights and conditions.
Vietnam	Gender Equality Advocacy	Nationwide	Vietnam Women's Union; UN Women Vietnam; Vietnamese Women's Rights Network	Ongoing since 2010	Campaigns and programs aim to improve women's rights and opportunities, focusing on legal reforms, public awareness campaigns, and increasing women's representation in various sectors.
Cambodia	Land Rights Campaigns	Phnom Penh, Rural Areas	Cambodian League for the Promotion and Defense of Human Rights (LICADHO); Community Legal Education Center (CLEC)	2012 - Present	Focused on combating land grabbing and securing land tenure for affected communities, LICADHO and CLEC work on legal advocacy, community mobilization, and policy reform to protect land rights.

The Cambodian League for the Promotion and Defense of Human Rights (LICADHO) has been a leading advocate for human rights in Cambodia since its establishment in 1992, focusing on issues such as land rights, forced evictions, and government accountability. Its core activities include monitoring and documenting human rights abuses, intervening in civil, political, economic, and social rights violations, and promoting accountability among state and non-state actors (Cambodian League for the Promotion and Defense of Human Rights, 2024). During World Habitat Day, LICADHO was pivotal in advocating for land rights. Between October 6 and 15, over 500 individuals from 13 land communities gathered in provinces such as Kampong Speu, Koh Kong, Kampot, and Banteay Meanchey to demand secure land tenure. In Trapeang Chor, community members highlighted forced evictions linked to sugarcane plantations, emphasizing the ongoing struggle for land security. LICADHO's efforts during this advocacy campaign underscore the urgent need to protect land rights and ensure equitable access to resources for marginalized communities.

The case studies from Singapore, Vietnam, and Cambodia provide valuable regional insights and lessons in addressing social justice challenges. They highlight the importance of community mobilization, as demonstrated by Cambodia's land rights campaigns and TWC2's advocacy for migrant workers in Singapore, showcasing the transformative power of grassroots involvement. Strengthening policy and legal frameworks is also crucial, with Vietnam's National Action Plan and Singapore's worker permit system as examples of how robust governance can drive sustainable reforms. Additionally, these case studies emphasize the need to focus on equity, particularly by addressing systemic inequities affecting marginalized groups, such as migrant workers, women, and Indigenous communities, to ensure inclusive and sustainable development across the region.

4.2. Comparison of Environmental Initiatives and Socio-economic Implications

The connection between environmental initiatives and socioeconomic impacts in the Philippines is assessed through Tables 4, 6, and 7, using Immediate Action, Timeliness, Effectiveness, and Long-Term Sustainability criteria. These criteria evaluate how initiatives address environmental crises while meeting socio-economic needs.

Immediate Action is vital for addressing crises like deforestation and pollution, as demonstrated in the relationship between Table 4 (environmental issues) and Table 6 (biodiversity impacts). Projects such as mangrove reforestation effectively combat deforestation and restore critical habitats, providing swift responses to protect ecosystems and communities. Timeliness is also crucial, as shown in Table 7, highlighting socio-economic impacts like disrupted livelihoods and health risks. Initiatives implemented on schedule, such as efficient waste management programs, achieve better community outcomes, whereas delays caused by resource shortages or bureaucratic obstacles reduce impact.

Effectiveness, analyzed through Tables 6 and 7, is reflected in measurable outcomes such as biodiversity conservation and improved livelihoods. Initiatives like sustainable agriculture achieve multiple objectives, improving food security while maintaining ecological balance and demonstrating how socio-economic considerations can be incorporated into environmental projects. Long-Term Sustainability relies on mechanisms that maintain ecological health and socio-economic benefits. Table 6 emphasizes the restoration of ecosystems, while Table 7 highlights the importance of community empowerment to ensure ongoing engagement and resilience. For example, renewable energy projects that include training programs equip communities with skills for long-term self-sufficiency, creating durable solutions. This analysis highlights the need for comprehensive strategies that integrate environmental and socio-economic goals, providing direction for equitable and sustainable development policies.

4.3. Comparison of Environmental Initiatives and Social Justice Movements

The intersection of environmental initiatives and social justice movements in the Philippines is analyzed using Tables 8 and 9. This section evaluates how these efforts impact marginalized communities by applying the criteria of Collective Responsibility, Community Engagement, Collaboration, and Social Justice and Equity.

Collective responsibility is a central theme across environmental initiatives (Table 8) and social justice movements (Table 9), highlighting shared accountability among stakeholders. For example, reforestation programs and land rights advocacy rely on the collaboration of governments, NGOs, and communities to achieve equitable outcomes. This collective effort underscores the importance of addressing systemic challenges through shared responsibility. Community engagement further amplifies these efforts, as participatory approaches in environmental initiatives, such as workshops and planning sessions, empower local voices in decision-making (Table 8). Similarly, grassroots participation in social justice movements

ensures that marginalized communities play a pivotal role in shaping policies (Table 9). This inclusive approach enhances the relevance and impact of both environmental and social justice initiatives.

Collaboration is another common feature, with environmental initiatives often involving inter-agency coordination and social justice movements forming coalitions among advocacy groups. These partnerships improve resource mobilization, capacity building, and the overall effectiveness of their efforts. Equity-focused initiatives also prioritize vulnerable populations. Environmental efforts, such as disaster risk reduction programs, target low-income communities (Table 8), while social justice movements advocate for the rights of Indigenous peoples and farmers (Table 9). These shared principles demonstrate the interconnectedness of environmental and social justice goals. These insights reveal that both spheres address intersecting challenges, advocating for systemic change that benefits the environment and marginalized populations.

4.4. Comparison of Interconnectedness Related to Sustainability

The interconnectedness between climate vulnerability and environmental issues is evident when evaluated through the Sustainable Practices and Long-Term Sustainability criteria, as illustrated in Tables 4 and 5. Sustainable practices are crucial for addressing vulnerabilities like flooding and food insecurity outlined in Table 5, which require adaptive solutions such as flood-resistant infrastructure and sustainable agriculture. Table 4 highlights environmental challenges, including deforestation and pollution, which exacerbate these vulnerabilities. Effective, sustainable practices must tackle these interconnected factors, promoting resilience through holistic and adaptive strategies.

Long-term sustainability emphasizes the need for ongoing efforts to build community resilience, as shown in Table 5. Initiatives like disaster preparedness and ecosystem restoration are vital in this process. However, Table 4 reveals that persistent environmental degradation, such as resource depletion and habitat loss, undermines these efforts. This underscores the importance of initiatives that restore natural resources and actively empower local populations to participate in sustainability measures. By addressing immediate and long-term vulnerabilities, sustainability initiatives can establish systems that adapt to evolving threats while fostering ecological and social resilience.

4.5. Comparison of Faith-Based Advocacy and Environmental and Social Justice Initiatives

This section analyzes the impact of faith-based advocacy in the Philippines and Southeast Asia on social justice and environmental stewardship, emphasizing the intersection of spiritual values and activism for vulnerable populations. Religious organizations, particularly the Catholic Church, are pivotal in advocating for the poor and leading environmental stewardship efforts. Interfaith collaborations further demonstrate how diverse religious beliefs unite to address social issues, fostering dialogue and cooperation on common goals such as disaster response and community development.

Central to this discussion is *Laudate Deum*, which provides a moral framework emphasizing interconnectedness, stewardship, and justice. It underscores the intrinsic value of all creation and the moral imperative to care for our common home. This framework inspires individuals, communities, and policymakers to engage in sustainable development, resource conservation, and the promotion of social equity. By fostering collective responsibility and community engagement, *Laudate Deum* addresses vulnerabilities exacerbated by environmental challenges, paving the way for a just and sustainable future.

Faith-based advocacy serves as a moral foundation for activism, highlighting compassion, stewardship, and social responsibility as essential components of both environmental and social justice movements. While these initiatives may face challenges, such as potential dogmatism,

they foster inclusive dialogue and collective action, enabling diverse communities to work toward shared objectives. To evaluate the impact of faith-based initiatives alongside social justice movements, this analysis applies the Access to Resources, Monitoring and Evaluation, and Sustainable Practices criteria, as outlined in Tables 9 and 10.

Tables 9 and 10 highlight various initiatives that reflect faith-based advocacy, aligning them with Catholic teachings on creation care and socio-economic equity, even before *Laudate Deum*'s official release on October 4, 2023. Faith-based advocates work to facilitate access to essential resources such as food, education, and healthcare for marginalized communities. These programs often focus on providing aid to impoverished families, ensuring they receive the necessary support to improve their living conditions.

In comparison, Table 9 showcases social justice movements that similarly prioritize access to resources. Movements advocating for farmers' rights, Indigenous people's rights, and housing rights demonstrate a shared commitment to equitable treatment of marginalized groups. Both faith-based initiatives and social justice movements emphasize that equitable access to resources is fundamental to achieving social equity.

Monitoring and evaluation mechanisms are critical for assessing the effectiveness of initiatives. Table 10 reveals that faith-based advocacy often incorporates spiritual and ethical frameworks into evaluation processes. These frameworks assess quantitative outcomes and qualitative aspects, such as community engagement and spiritual development. For instance, faith-based initiatives may measure their success by examining participants' sense of community and spiritual growth.

Conversely, Table 9 illustrates the evaluation methods used by social justice movements, which often employ participatory approaches. These methods include community feedback, surveys, and impact assessments prioritizing the voices of those directly affected. Participatory evaluation ensures that initiatives remain relevant and effective in addressing community needs. The differences in evaluation approaches between faith-based initiatives and social justice movements highlight the diverse ways organizations measure their effectiveness.

Sustainability is crucial for ensuring the long-term viability of initiatives. Table 10 demonstrates that faith-based initiatives frequently incorporate sustainability principles into their programs, reflecting a commitment to environmental stewardship rooted in spiritual teachings. These activities include community gardening, renewable energy projects, and conservation efforts, all emphasizing the moral obligation to care for creation.

Similarly, Table 9 showcases social justice movements that integrate sustainability into their advocacy efforts. For instance, initiatives focused on sustainable agriculture empower local farmers by ensuring fair access to markets and resources. Both faith-based initiatives and social justice movements recognize that social and environmental issues are interconnected, and their alignment with sustainable practices underscores the importance of addressing these challenges holistically.

The comparison between faith-based advocacy and environmental and social justice initiatives in the Philippines reveals significant overlap in their goals and approaches. By applying the Access to Resources, Monitoring and Evaluation, and Sustainable Practices criteria, it is evident that both sectors are committed to promoting social equity and environmental stewardship. Their collaborative efforts can enhance the impact of initiatives supporting vulnerable populations and addressing systemic inequalities.

This synergy aligns with the principles of *Laudate Deum*, which emphasizes the need for a holistic approach to environmental and social justice. These combined efforts can drive

meaningful change in the Philippines and Southeast Asia by fostering a culture of care and responsibility for creation and its inhabitants.

5. CONCLUSION

This study underscores the interconnectedness of environmental initiatives and social justice movements in the Philippines, a nation rich in biodiversity but deeply vulnerable to climate change and socio-economic inequities. By evaluating these efforts through the principles of *Laudate Deum*, the research highlights the importance of aligning ecological restoration with social equity, community resilience, and collaborative action. While initiatives such as mangrove reforestation and community-based waste management demonstrate the potential of participatory approaches to promote both ecological and socio-economic benefits, challenges persist in ensuring long-term sustainability and equitable resource distribution. Social justice movements, including campaigns for Indigenous land rights, urban housing reform, and sustainable agricultural practices, play a critical role in addressing systemic inequities and empowering marginalized communities to participate in decision-making. Faith-based advocacy further enriches these efforts by integrating moral and ethical principles that emphasize stewardship, interconnectedness, and equity, inspiring collective action and fostering partnerships for sustainable development.

The study emphasizes that collaboration among environmental organizations, social justice movements, and faith-based groups is essential for amplifying impact, pooling resources, and addressing shared challenges. Policymakers must ensure that environmental initiatives align with socio-economic priorities, incorporating marginalized voices into decision-making and strengthening enforcement mechanisms. To advance sustainability and equity, increased awareness of *Laudate Deum* principles through education and community outreach is vital, as is showcasing successful case studies to motivate participatory conservation efforts. Policymakers should promote sustainable land use, support vulnerable communities, and enhance enforcement mechanisms. Partnerships across sectors, interdisciplinary research on faith-based advocacy and social justice, and robust monitoring frameworks will be critical to fostering resilience and ensuring long-term sustainability. By adopting these recommendations, stakeholders can address environmental and social challenges holistically, creating equitable and sustainable communities guided by the unifying vision of *Laudate Deum*.

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OVERVIEW OF NIGERIA'S INFRASTRUCTURAL DEVELOPMENT

Muhammad Onoruiza Audu[1], Otu Muhammed Adeiza[1*]

[1] *Department of Architecture, Confluence University of Science and Technology, Osara, Nigeria*

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ABSTRACT

This paper offers a comprehensive analysis of Nigeria's infrastructural development from 2014 to 2023, focusing on significant achievements and recurring challenges. The study examines key projects in transportation, energy, and housing, such as the Abuja-Kaduna and Lagos-Ibadan railways, the Azura-Edo Power Plant, and urban road upgrades. Persistent issues, including insufficient funding, regulatory inefficiencies, regional disparities, and security challenges, are also assessed. Using a mixed-methods approach that incorporates a literature review, data analysis, and stakeholder perspectives, the research evaluates the social and economic effects of these initiatives. The findings provide strategic recommendations to improve infrastructure quality and accessibility, promote sustainable practices, and support long-term economic development.

Keywords: Infrastructural development; Transportation projects; Energy sector; Economic impact; Sustainable growth

1. INTRODUCTION

Infrastructure encompasses facilities and services provided by the government to enhance economic productivity and elevate citizens' quality of life. A robust infrastructure foundation enables the delivery of improved services, contributing to higher overall economic output. Investments in infrastructure, such as roads, electricity, and water supply, act as essential inputs for production processes. The critical role that infrastructure plays in boosting productivity and enhancing citizens' living standards makes the assessment of Nigeria's infrastructural progress a matter of significant importance.

However, despite its importance, prior research points to ongoing issues such as inadequate infrastructure, funding shortages, and regulatory hurdles, which have hindered progress and efficiency in service delivery. For example, limited access to dependable transportation and electricity has negatively impacted economic activities and the broader developmental trajectory of the country (Obi et al., 2019; Eze et al., 2021). Establishing a solid infrastructure base is crucial for fostering economic growth, as it enhances productivity and facilitates more effective service delivery. Furthermore, investments in key sectors like transportation, electricity, and water resources are fundamental to achieving economic stability and long-term development.

Infrastructure refers to physical systems that enhance societal living standards, such as healthcare and agricultural facilities, transportation networks, telecommunication systems, energy infrastructure, and water provision services (Babu et al., 2022; Baig et al., 2022). Infrastructure services significantly enhance the productivity of other economic factors and are often referred to as the "unpaid factor of production." Moreover, investment in infrastructure attracts additional resource inflows to a region (Mukwaya and Mold, 2018). While the economic contributions of

*Corresponding author's email: otuma@custech.edu.ng
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infrastructure may take time to materialize, they remain a reliable path for developing countries to achieve long-term economic sustainability (Chan et al., 2022). Strategic planning, political will, and a robust procurement approach are crucial for realizing the long-term benefits of infrastructure development.

Infrastructure is critical as it provides services essential for daily consumption and serves as inputs into private-sector production. It drives the productivity of capital and labor in producing goods and services, forming the backbone of national economies and supporting livelihoods through employment and income generation (Bilal et al., 2022). Recent studies emphasize the wide range of services encompassed by infrastructure, including highways, roads, safety standards, mass transit, airport facilities, electricity, gas and water supply systems, wastewater treatment, solid waste management, stormwater drainage, and sewerage disposal systems. Other critical facilities include correctional institutions, educational facilities, public health delivery systems, emergency response systems, and law enforcement (World Bank, 2022). These systems play a crucial role in supporting sustainable economic development by improving supply chain effectiveness and lowering the costs associated with trade (Yang et al., 2020).

This study aims to examine major infrastructure projects and their economic outcomes, while also identifying obstacles such as funding limitations and regulatory shortcomings. It evaluates the effectiveness of government initiatives and policy reforms, with a focus on developments in critical sectors like power, transportation, and housing. The analysis emphasizes both achievements and persistent issues in these areas. Ultimately, this study aims to propose strategic recommendations to address these challenges, improve infrastructure quality and accessibility, and promote sustainable practices for future development.

This study has several key scopes. The Content Scope examines various aspects of Nigeria's infrastructural development, focusing on the transportation, energy, and housing sectors. The Geographical Scope includes Nigeria as a whole, with particular emphasis on regions or states with significant infrastructure projects. The Methodological Scope involves comprehensive data collection from government reports, infrastructure assessments, and expert interviews. Finally, the Time Scope focuses on the period from 2014 to 2023, analyzing key projects, challenges, and developments in Nigeria's infrastructure during this timeframe.

2. LITERATURE STUDY

2.1. Classification of Infrastructure

Infrastructure can be classified based on consumption characteristics and functional roles. Some types of infrastructure allow for simultaneous usage by multiple individuals without diminishing the quality or availability of the service to others. These are termed non-exclusionary services, meaning it is costly or impractical to exclude anyone from using them once they are available. This phenomenon, often leading to free-riding, is common in certain infrastructure services (Berg et al., 2021). However, when infrastructure does not exhibit this characteristic, it is categorized as either private goods or club goods, depending on ownership and control rights. Examples include power, roads, and water, which can be classified as either private or club goods based on property and control rights allocations (Jones & Simmons, 2020).

Another approach to classifying infrastructure is based on their functional roles, which leads to two primary categories: core infrastructure and basic infrastructure.

1. Core Infrastructure

   Core infrastructure includes road networks, water supply, electricity, and telecommunications. These infrastructures serve as intermediate inputs in private-sector output, enhancing economic activities. Additionally, some core infrastructure types also act as final goods, as the services they provide are directly consumed by residents. For

instance, roads facilitate transportation for businesses and individuals alike, while electricity and water supply are essential for daily living and industrial activities (Smith et al., 2022; Zhao & Chen, 2023).

2. Basic Infrastructure
   Basic infrastructure, often referred to as public capital, provides services that are de facto public goods. These include infrastructures that are challenging to exclude individuals from using, regardless of their contribution to deployment or maintenance. Public health systems, education facilities, and safety services (like law enforcement and fire services) fall under this category (Brown & Green, 2021). The private sector is typically less inclined to invest in basic infrastructure due to the difficulty in excluding non-payers, resulting in these areas often being underserved. Consequently, basic infrastructure relies heavily on public sector investment and maintenance to meet societal needs (Taylor & Wills, 2022; Hernandez, 2023).

This classification highlights the diverse nature of infrastructure services and their vital role in supporting both private-sector productivity and public welfare. Understanding these differences is essential for policymakers to distribute resources efficiently and meet the diverse requirements of various types of infrastructure.

2.2. Selected Core Infrastructures in Nigeria

2.2.1. The Nigerian Railway

Between 2014 and 2023, Nigeria's railway system experienced considerable transformation, reflecting extensive modernization and development. One prominent accomplishment is the Abuja-Kaduna railway, launched in July 2016, which shortened travel times between the two cities while improving passenger safety and convenience. This $870 million initiative represents a pivotal aspect of Nigeria's comprehensive efforts to rejuvenate its rail infrastructure. Another significant project is the Lagos-Ibadan railway, inaugurated in June 2021, which reduced travel time between Lagos and Ibadan to approximately 1.5 hours, facilitating economic activities and alleviating road congestion.

Further advancement includes the Lagos Rail Mass Transit (Blue Line) project and the Kano-Maradi railway. The Blue Line, a part of the Lagos Urban Rail initiative, was designed to tackle urban transportation challenges and is projected to serve up to 500,000 passengers daily upon full operation. Despite delays, substantial milestones were achieved, with major sections completed by 2022. Similarly, work on the Kano-Maradi railway began in 2021 and is anticipated to boost trade between Nigeria and Niger, strengthening regional economic ties. These initiatives reflect Nigeria's commitment to upgrading its rail network, facilitated by public-private partnerships and legislative reforms aimed at attracting private sector investments and enhancing regulatory frameworks.

2.2.2. The Nigerian Roads

Nigeria has the most extensive road network in West Africa, spanning approximately 195,000 km, with roughly 60,000 km paved. However, many of the major roads built in the 1980s and early 1990s have severely deteriorated due to insufficient maintenance and the use of low-quality repair materials. This deterioration has made travel particularly difficult during the rainy season, with potholes and eroded surfaces posing serious safety risks.

The nation's key highways, such as A1, A2, A3, and A4, extend from the southern regions to the north, facilitating the transport of goods from inland areas to coastal ports for export. Trunk Road "A," the primary component of the national road network, is managed by the Federal Ministry of

Works and Housing, while Trunk Roads "B" and "C" fall under the jurisdiction of state and local governments. Despite their importance, these roads have suffered from decades of neglect, limited funding, and poor maintenance practices, resulting in their substantial decline.

The Nigerian government has undertaken various initiatives to tackle these challenges, including a 2018 budget allocation of N295 billion for road maintenance and infrastructure projects (Federal Highway System of Nigeria). Notable advancements include the rehabilitation and widening of the Lagos-Ibadan expressway. Furthermore, data from the AmeriGEOSS (Americas Group on Earth Observations System of Systems) Community Platform highlights ongoing efforts to modernize and maintain road networks through advanced technologies and real-time data from platforms like OpenStreetMap. These measures are designed to enhance road quality, reduce travel durations, and improve user safety. Despite these efforts, significant challenges remain, such as ensuring consistent maintenance, adopting higher construction standards, and improving the management of funds. Resolving these issues is essential for promoting economic development and enhancing the well-being of Nigerians, who depend heavily on the road system.

2.2.3. Nigeria’s Refinery

Between 2014 and 2023, Nigeria's oil sector faced numerous challenges alongside emerging opportunities. Crude oil production struggled to reach previous high levels, maintaining an average output of 1.4 to 1.5 million barrels per day (bpd) due to inefficiencies in operations, frequent pipeline vandalism, and security threats in the Niger Delta. The nation’s refineries, including those in Port Harcourt, Warri, and Kaduna, operated well below capacity and faced persistent technical issues, with revitalization projects hampered by delays and budgetary limitations (Oluwaseun, 2022; Olatunji, 2023). Despite these setbacks, the oil industry remains a cornerstone of Nigeria's economy, contributing roughly 90% of government revenue.

Recent developments include the construction of the Dangote Refinery, poised to become the world’s largest single-train refinery. This project is expected to enhance Nigeria’s refining capacity and reduce reliance on imported refined products (Nigerian National Petroleum Corporation, 2023). The Federal Government has introduced reforms to improve refinery efficiency and encourage private sector investment. However, environmental challenges, such as oil spills and gas flaring, along with ongoing security concerns in the Niger Delta, continue to pose significant obstacles (Adams, 2021; Egbejule, 2022; Akinwale, 2024; Olajide, 2023; Nwogugu, 2023).

2.2.4. Nigeria’s Power Supply

Between 2014 and 2023, Nigeria’s power supply sector faced considerable challenges despite ongoing reforms and investment initiatives. The country’s power generation capacity remained insufficient, averaging around 4,000 to 5,000 megawatts (MW), which is inadequate for a population exceeding 200 million. Frequent power outages and load shedding continue to disrupt consumers due to outdated infrastructure, operational inefficiencies, and insufficient investment (Akinwale, 2023; Olowofela, 2023).

The restructuring of the Power Holding Company of Nigeria (PHCN) into 18 entities in 2005 aimed to enhance the sector, but progress has been sluggish. Regulatory and funding issues persist, impacting the effectiveness of these reforms (Eze, 2021; Nwachukwu, 2022). Independent Power Producers (IPPs) have played a crucial role in augmenting Nigeria’s power supply, with projects like the Azura-Edo Independent Power Plant and upgrades to the Kainji Hydro Power Station. Despite these efforts, the sector continues to grapple with regulatory challenges and the need for further investment to ensure reliable power delivery (Oluwaseun, 2023; Adeyemi, 2024). The National Electricity Regulatory Commission (NERC) has made

strides in issuing licenses and overseeing the sector, but comprehensive improvements are still needed to address power supply issues effectively.

3. RESEARCH METHOD

The assessment of Nigeria's infrastructural development from 2014 to 2023 employed a multidimensional methodology comprising a literature review, data collection, case studies, and stakeholder analysis. The process began with an in-depth review of academic journals, government reports, policy documents, and industry publications to establish a foundational understanding of the advancements, challenges, and impacts of infrastructure projects. Quantitative data from official sources, such as the Nigerian Bureau of Statistics, and qualitative insights from interviews with stakeholders were integrated to build a comprehensive data set. Case studies of key projects, including the Lagos-Ibadan Expressway and the Azura-Edo Independent Power Plant, were examined to highlight best practices and recurring challenges.

Furthermore, a comparative analysis with other African nations was conducted using benchmarks and performance metrics to pinpoint Nigeria's relative advantages and shortcomings in infrastructural growth. The study also assessed the economic, social, and environmental impacts of major projects through statistical analysis. The evaluation of government policies and reforms focused on their effectiveness in shaping development outcomes, while a SWOT analysis identified internal and external factors influencing progress.

The outcomes of this methodology were synthesized into a detailed report aimed at providing actionable insights for policymakers and stakeholders. This approach ensured a thorough evaluation and generated practical recommendations to improve the quality and accessibility of Nigeria's infrastructure.

4. RESULTS

4.1. Assessment of Progress and Achievements in Nigeria's Infrastructural Development (2014 – 2023)

Between 2014 and 2023, Nigeria implemented several infrastructural projects to address critical gaps and drive economic growth. A review of notable achievements highlights substantial advancements in key sectors, particularly transportation and power. The Lagos-Ibadan Expressway, a vital route linking major economic centers, underwent significant rehabilitation and expansion, resulting in reduced travel times and improved logistical efficiency (Adeoye, 2022). Likewise, the completion of the Second Niger Bridge, a long-delayed project, strengthened connectivity between the southeastern and southwestern regions, facilitating trade and mobility (Salami, 2023).

In the rail sector, the Abuja-Kaduna railway line emerged as a landmark accomplishment. Launched in 2016, it provided a dependable alternative to road travel, greatly enhancing passenger and freight transport (Oluwaseun, 2023). The government also embarked on various urban renewal initiatives, including the construction of new roads, bridges, and flyovers in major cities such as Lagos, Abuja, and Port Harcourt. These developments aimed to alleviate traffic congestion and improve urban mobility (Nwachukwu, 2022). Collectively, these efforts have advanced Nigeria's economic growth by improving infrastructure quality, generating employment opportunities, and attracting investments.

In the power sector, despite persistent challenges, significant progress has been made. The Azura-Edo Independent Power Plant, commissioned in 2018, contributed an additional 461 megawatts to the national grid, partially alleviating power supply constraints (Olowofela, 2023). Various

solar projects were also launched, particularly in rural areas, to diversify energy sources and improve electricity access. These efforts, supported by reforms such as the partial privatization of the power sector, aimed to increase generation capacity and operational efficiency (Eze, 2021). Despite these advancements, outdated infrastructure and frequent outages continue to hinder reliable power delivery.

4.2. Challenges and Barriers in Nigeria's Infrastructural Development (20`4 – 2023)

Despite significant investments and achievements, numerous challenges and barriers have impeded optimal progress in Nigeria's infrastructural development. A critical issue has been the inconsistent and inadequate funding of infrastructure projects. Budget constraints and delays in fund disbursement have frequently stalled projects, leading to cost overruns and extended completion times. This financial shortfall is exacerbated by Nigeria's economic volatility, heavily influenced by fluctuations in global oil prices, which impact government revenues and allocations to infrastructure projects (Adeyemi, 2024).

Regulatory and bureaucratic inefficiencies present significant obstacles, with complex and time-consuming approval processes frequently delaying project execution. Corruption and poor management within governmental institutions have further impeded progress by misallocating funds and resources, leading to substandard infrastructure that fails to meet global benchmarks (Nwachukwu, 2022).

Another critical issue is the uneven distribution of infrastructure development. Urban areas like Lagos, Abuja, and Port Harcourt have experienced notable advancements, while rural and less prosperous regions continue to lag, deepening regional inequalities and stalling inclusive economic progress.

The power sector is also constrained by outdated facilities and insufficient maintenance, resulting in frequent power outages and unreliable electricity supply. Despite ongoing reforms and investments, the sector remains hindered by limited generation capacity and inefficient distribution networks, adversely affecting both residential and industrial users (Olowofela, 2023; Eze, 2021).

Security challenges, especially in northeastern Nigeria, have further disrupted infrastructure development. Persistent conflicts and insurgencies have made project implementation challenging, often diverting resources toward security efforts. Environmental factors such as flooding and erosion also pose additional risks, necessitating investments in resilience and sustainable infrastructure solutions (Salami, 2023).

Effectively addressing these complex challenges will require a holistic strategy, including enhanced funding mechanisms, streamlined regulatory systems, increased transparency, and focused investments to promote equitable regional development and ensure long-term infrastructure viability.

4.3. Government Policies and Reforms in Nigeria's Infrastructural Development (2014 – 2023)

Between 2014 and 2023, the Nigerian government introduced various policies and reforms to enhance infrastructural development. The National Integrated Infrastructure Master Plan (NIIMP) provided a comprehensive roadmap for infrastructure investment, focusing on key areas such as transportation, energy, housing, and water resources. This strategic initiative aimed to align infrastructure projects with national development objectives, fostering coordinated and sustained growth across sectors (Adeyemi, 2024).

One notable policy was the adoption of public-private partnerships (PPPs) to attract private-sector funding and expertise. The Infrastructure Concession Regulatory Commission (ICRC) was

established to facilitate these partnerships, resulting in significant projects like the Lekki Deep Sea Port and the Lagos-Ibadan railway line. These partnerships have helped address funding gaps and improve project implementation by leveraging private-sector efficiency (Nwachukwu, 2022). Nevertheless, some PPP projects have encountered delays and contractual disputes due to regulatory ambiguities and governance issues.

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The government also pursued housing policies to tackle the significant housing deficit. The National Housing Programme (NHP) and initiatives such as the Family Homes Fund (FHF) sought to deliver affordable housing units and provide low-cost financing. While these programs have improved homeownership among low- and middle-income earners, high construction costs, land acquisition issues, and bureaucratic delays have hindered effective implementation (Eze, 2021).

While government policies and reforms have laid a solid foundation for infrastructural development, their impact has been uneven. Addressing regulatory challenges, ensuring effective governance, and fostering a conducive environment for private-sector participation remain critical to achieving sustainable infrastructural growth.

4.4. Impact of Infrastructural Development on Nigeria's Economic Growth and Quality of Life (2014 – 2023)

The period from 2014 to 2023 saw significant investments in Nigeria's infrastructure, yielding both direct and indirect impacts on economic growth and quality of life.

Transportation infrastructure improvements, such as the Lagos-Ibadan Expressway rehabilitation and Abuja-Kaduna railway construction, enhanced connectivity and reduced travel times. These projects facilitated goods and people movement, boosting trade and commerce while attracting investments (Adeoye, 2022). The Lekki Deep Sea Port expanded maritime trade capacity, positioning Nigeria as a regional logistics hub and creating job opportunities (Salami, 2023).

In the power sector, improved electricity generation and distribution supported industrial and commercial operations. The Azura-Edo Independent Power Plant increased electricity supply, essential for business productivity and economic growth. However, frequent power outages and inefficiencies hinder the full realization of these benefits (Olowofela, 2023).

Housing initiatives such as the NHP and FHF improved access to affordable housing, stimulated the construction sector, and created jobs. Enhanced housing conditions contributed to better health outcomes and reduced informal settlements, promoting quality of life (Eze, 2021).

Infrastructure development has also improved access to healthcare, education, and clean water, particularly in rural areas. However, significant regional disparities remain, as rural areas continue to fall behind urban centers in both infrastructure quality and availability (Nwachukwu, 2022).

In summary, Nigeria's infrastructural development efforts from 2014 to 2023 have contributed positively to economic growth and improved living standards. Despite these achievements, persistent issues such as limited funding, regulatory challenges, and regional imbalances need to be resolved to achieve sustainable and inclusive development.

4.5. Strategic Recommendations to Address and Enhance Nigeria's Infrastructural Development (2014 – 2023)

To address the challenges and optimize Nigeria's infrastructural development from 2014 to 2023, the study proposes several strategic recommendations:

1. Diversify and Enhance Funding Mechanisms
   Broaden Funding Sources: Nigeria should adopt a variety of funding strategies beyond the conventional reliance on government budgets and oil revenue. These strategies could include utilizing public-private partnerships (PPPs), securing international loans, and issuing infrastructure bonds. A diversified funding approach would provide the capital needed for large-scale infrastructure projects while reducing dependence on oil revenues, which are vulnerable to market volatility (Adeyemi, 2024). Strengthening the capacity of the Infrastructure Concession Regulatory Commission (ICRC) to effectively manage and support these partnerships would further enhance project execution and mitigate associated risks.
   Implement Financial Innovations: Nigeria can benefit from innovative financing models such as blended finance, which integrates public and private funding, and infrastructure investment trusts designed to attract global investors. Moreover, implementing a more transparent and efficient budget allocation system would help reduce delays in funding and streamline project implementation (Nwachukwu, 2022).
2. Strengthen Regulatory and Institutional Frameworks
   Streamline Regulatory Processes: Regulatory approval processes for infrastructure projects should be streamlined to reduce delays and eliminate bureaucratic inefficiencies. Leveraging digital platforms for project approvals and monitoring can significantly improve transparency and operational efficiency, facilitating quicker project implementation (Salami, 2023).
   Enhance Governance and Anti-Corruption Measures: Governance frameworks must be reinforced to ensure proper use of funds and successful project execution. This can be achieved through stricter oversight mechanisms, regular audits, and greater transparency. Such measures will help address corruption and mismanagement, ensuring that resources are allocated effectively (Eze, 2021).
3. Address Regional and Sectoral Disparities
   Focus on Inclusive Development: Infrastructure development should focus on underserved and rural regions to reduce regional disparities and ensure equitable progress. Investments in rural roads, electrification, and access to essential services are crucial to fostering balanced regional growth, minimizing economic inequalities, and promoting inclusivity (Olowofela, 2023).
   Support Sector-Specific Initiatives: Customized approaches are necessary to tackle unique challenges in key sectors like power, transportation, and housing. For instance, upgrading grid infrastructure and incorporating renewable energy sources can improve reliability and capacity in the power sector. Similarly, advancing major road and rail projects and enhancing urban transit systems will strengthen connectivity and stimulate economic activity (Nwachukwu, 2022).
4. Promote Technological Integration and Infrastructure Maintenance

Adopt Advanced Technologies: Modern technologies and best practices should be integrated into infrastructure development and maintenance. Smart systems, such as automated traffic management and energy-efficient technologies, can improve operational efficiency while promoting sustainability (Adeoye, 2022).

Develop Robust Maintenance Strategies: Comprehensive maintenance plans are crucial for preserving infrastructure assets and ensuring their reliability. Routine upkeep and timely upgrades are necessary to prevent deterioration and avoid service interruptions (Olowofela, 2023)

5. Enhance Environmental and Social Sustainability

   Integrate Environmental Considerations: Infrastructure projects should prioritize environmental sustainability by employing green construction techniques, minimizing ecological impacts, and investing in climate-resilient designs. These efforts will mitigate long-term environmental risks and support sustainable development goals (Salami, 2023).

   Engage with Communities: Actively involving local communities in the planning and implementation of infrastructure projects is essential to address their specific needs and expectations. Such engagement can improve public acceptance, resolve localized challenges, and strengthen social cohesion (Eze, 2021).

In conclusion, adopting a multifaceted approach that includes diversifying funding sources, simplifying regulatory frameworks, addressing regional inequalities, leveraging advanced technologies, and ensuring environmental and social sustainability will enable Nigeria to address its infrastructural challenges effectively. These strategies aim to promote sustainable growth, enhance living standards, and drive long-term economic progress.

5. CONCLUSION

This paper has examined Nigeria's infrastructure development between 2014 and 2023, focusing on critical sectors such as railways, roads, refineries, and power supply. The analysis underscores the pivotal role of infrastructure in boosting productivity, enhancing living standards, and driving sustainable economic growth. While progress has been achieved in areas such as the Abuja-Kaduna and Lagos-Ibadan railways and the ongoing Dangote Refinery project, the sector continues to face significant challenges, including insufficient funding, regulatory obstacles, inadequate maintenance, and regional inequalities.

The findings from core infrastructure projects emphasize the importance of sustained investment, particularly in modernization and maintenance. Although the railway system has seen improvements, these advancements are often delayed due to funding shortages. Similarly, Nigeria's road network suffers from extensive deterioration despite its breadth, while the energy sector continues to struggle with inefficiencies and capacity limitations. Additionally, the country's power supply remains critically insufficient for its expanding population, with sector reforms showing limited success.

Addressing these issues through the strategic recommendations presented in this study will enable Nigeria to build a more resilient and sustainable infrastructure framework. Key actions include diversifying funding mechanisms, streamlining regulatory processes, ensuring equitable resource allocation across regions, adopting advanced technologies, and prioritizing environmental and social sustainability. These steps are essential for promoting inclusive growth, ensuring long-term economic stability, and improving living conditions. Implementing these measures will

position Nigeria's infrastructure to be robust, adaptable, and aligned with its national development objectives.

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